TEST OF AN AMMONIA REFRIGERATING MACHINE

BY

GOODRICH QUIGG LEWIS
FLOYD JAMES MACKEY
FRANK G ROMIG

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN MECHANICAL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

OF THE

UNIVERSITY OF ILLINOIS

JUNE, 1910

UNIVERSITY OF ILLINOIS

May 31 1910

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Goodrich Quigg Lewis, Floyd James Mackey and Frank G. Romig

ENTITLED Test of an Ammonia Refrigerating Machine

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

J. A. Thorpe
Instructor in Charge.

APPROVED: G. A. Goodenough

HEAD OF DEPARTMENT OF Mechanical Engineering

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TEST OF AN AMMONIA ICE MACHINE.

The object of this thesis is to present the results of a series of five tests made upon the York Compression ice machine in the Machinical Engineering Laboratory of the University of Illinois. The purpose of these tests was to determine the effect upon the several efficiencies of the installation for a range of five different compressor back pressures, with other conditions maintained as constant. A short outline of the theory, history and development of mechanical refrigeration, with special reference to the ammonia compression system, is given introductory to the description and results of the investigation.

The theory and practice of mechanical refrigeration are based upon the two first laws of thermodynamics, namely: (1), that mechanical energy is convertable into heat and vica versa: (2), that an external agent is necessary to enable heat to pass from a cold body to a hot one. The compression of a given weight of gas causes a rise in its temperature and consequently a rise in its store of heat energy. Upon expansion the work performed is done at the expense of this supply. Therefore, if some gas as, for example, air, be compressed and then cooled by passing it through water at a lower temperature so that it has been reduced to about the temperature before compression, and then be allowed to expand until its original pressure has been regained, the work done will be performed at the expense of the reduced stock of heat, i.e. the heat taken away from the air by the cooling water. The air having lost a large portion of its heat in this manner undergoes a given reduction in temperature , which gives rise to that negative condition known as cold. The work demanded from a refrigerating machine is that required to extract heat from a cold body, such as the air in an enclosed space. By employing mechanical energy, the temperature of this heat supply is sufficiently raised to admit of its being carried away by a suitable external agent. This agent is water, in most cases, because of its cheapness and because it has a greater capacity for heat, weight for weight, than any other known substance.

The main principle involved in the process is that the temperature of the agent must be raised above that of the water available for cooling purposes. The exact amount of temperature increase must be regulated by the required temperature of the medium or agent, upon leaving the expansion cylinder. Another vital necessity is the provision of a suitable cooling medium, usually water, for taking up the heat given from the medium to be cooled. The cooling water is either run to waste or recooled for further use.

Refrigeration is, therefore, the abstraction of heat from one body and its transfer to another called the refrigerating agent. This is the main function of all refrigerating and ice making apparatus. In order to secure continuity of action the refrigerating agent must be either periodically renewed, or suitable means provided for the removal of the heat extracted from the material cooled. A continuously acting machine comprises a heat abstracting apparatus and a suitable means for automatically renewing the refrigerating agent itself, or restoring its required condition, at the proper time.

The art of refrigeration and ice making is supposed to have originated in India at a very remote period, and the ancient methods are still being practiced by the natives of that country. One of the principal methods is to place shallow pans made of a porous material and filled with water, upon beds of straw, corn-stalks or some other similar insulator. Exposed to the night air under favorable conditions of wind and weather, the vessels become covered with thin sheets of ice. The ancient Romans probably cooled their wine by immersing the bottles in an agitated solution of salt petre and water.

The first recorded use of artificial cold is by Blasius Villafranka, a physician of Rome, who utilised it in practice as early as 1550. The freezing of water by means of a mixture of ice and salt petre is mentioned by Latinus Tancredus of Naples in 1607, and in all probability this is the method used by the Estronian tribe to freeze dead bodies as, mentioned by Orosius about 400 A. D.

It is only during recent years that the art has been extensively developed on a commercial basis. This has been brought about through the efforts of competant engineers and manufacturers, and at the present time , refrigeration and ice making has become an extensive industry throughout the civilized world. The various inventions for refrigerating and ice making purposes now in use for commercial purposes may be classified as follows.

1. Those wherein the more or less rapid disolution or liquefication of a solid is utilized to abstract heat. This is, strictly speaking, a chemical process more than a mechanical one.

2. Those wherein the abstraction of heat is effected by the evaporation of a portion of the liquid to be cooled, the process being assisted by the air pump. This is known as the Vacuum

System.

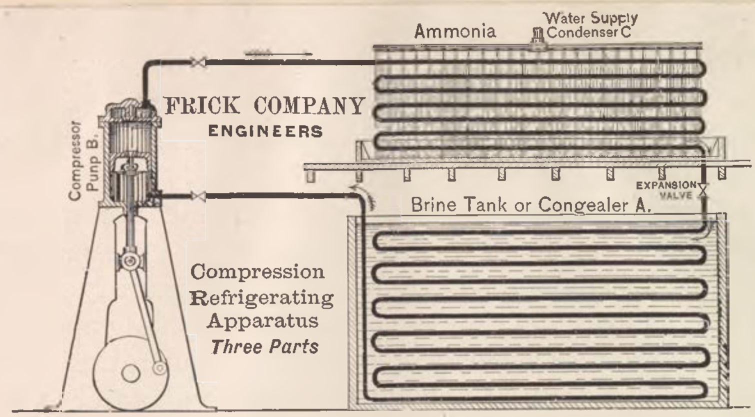
3. Those wherein the abstraction of heat is effected by by the evaporation of a separate medium of a more or less volatile nature which agent is subsequently restored to its physical condition by mechanical compression and cooling. This is called the Mechanical Compression System.

4. Those wherein the abstraction of heat is effected by evaporation of a separate refrigerating agent of a more or less volatile nature under the direct action of heat, which agent enters into solution with a liquid. This is termed the Absorbtion System.

5. Those wherein air or other gas is first compressed, then cooled and afterwards permitted to expand while doing work, or practically, by applying heat so as to automatically produce cold. These are usually designated as cold air machines.

Experience has developed the most practical and most successful method, viz: the Mechanical Compression System using anhydrous ammonia as the refrigerating agent. In the year 1755, Dr. Cullen discovered that by removing atmospheric pressure ether and other liquids which boil at low temperatures, would evaporate at temperatures below the freezing point, with sufficient rapidity to congeal water brought into contact with the exterior surfaces of the retaining vessels. The Compression System was first introduced by Jacob Perkins in the year 1834 and this invention was the beginning of all compression machines, for the purpose of refrigerating and ice making.

THE AMMONIA COMPRESSION SYSTEM.



OUTLINE DRAWING OF MECHANICAL-COMPRESSION SYSTEM

Fig. 1

The cycle of operation in the ammonia compression system is of course continuous, the only loss of agent being through leakage. The cycle is illustrated by fig. 1 and is divided into the following stages.

1. COMPRESSION OF THE REFRIGERATING AGENT. This is carried on in the compressor pump B, where the agent is subjected to a pressure great enough so that it can be liquified later by the condenser at a given temperature. During compression a degree of heat is developed according to the pressure rise.

2. CONDENSATION. Condensation takes place in the Condenser C. The heat of compression is taken away by forcing the gas through water cooled pipes which causes a transfer to the cooling water. The gas is then ready to assume a liquid state, and in changing from a gas to a liquid the agent gives off an additional amount of heat to the cooling water which is the latent heat of liquefaction.

3. EXPANSION. The agent is next allowed to pass through the expansion valve and, being suddenly relieved of pressure, it instantly expands or flashes back into the gaseous state. In this action, it takes up a quantity of heat which it renders latent. The materials from which this heat is drawn comprise such substances as may be in contact with the pipes, such as air, brine, water etc. The substance surrounding the expansion pipes in Fig 1. is the brine contained in the tank A. The amount of heat here absorbed is equal to the amount previously absorbed by the cooling water in the compressor jacket plus the amount absorbed by the cooling water of the condenser. The gas is again ready for compression and thus the process is repeated, the only renewal of the agent being that required by leakage. The compression machine must therefore have three principle parts, namely

1. The Compressor
2. The Condensing Apparatus
3. The Expansion Apparatus

PROPERTIES OF ANHYDROUS AMMONIA.

Ammonia machines use anhydrous ammonia (NH_3) as a refrigerating agent. It s latent heat of vaporization is large and for this reason it is a good refrigerant. Next to water it has the greatest heat absorbing powers of any of the fluids and can be liquified at comparatively low pressure. Its principal disadvantages are that it is somewhat impractical for use in marine service, that it is inflammable and explosive , and that it acts as an irritant poison in case of escape. Anhydrous ammonia has a molecular weight of 17, a density of 8.5, a latent heat of vaporization of 900 B. t. u. per pound, and a vapor tension of 108 pounds per square inch at a temperature of 70 degrees F. It is a gas which can be liquefied at a pressure of 128 pounds per square inch at a temperature of 70 degrees F. and at a pressure of 150 pounds per square inch at a temperature of 77 degrees F. The pressure required to liquefy rises very rapidly with the rise in temperature. The commercial produce is handled as a liquid in tanks under pressure and usually contains less than 0.03 per cent of moisture. Further properties of the gas are given in tables 1 and 2.

TABLE 1.

Properties of Saturated Ammonia

Temperature		Pressure p (From a Vacuum)		Heat of Vaporization Thermal Units	External Heat, Thermal Units	Internal Heat, Thermal Units	Volume of Vapor per Pound	Volume of Liquid per Pound	Weight of *Cubic Foot* of Vapor, Pounds	Weight of *Cubic Foot* of Liquid, Pounds	Gauge Pressures per Square Inch
Degree F t	Absolute T	Pounds per Square Foot P	Pounds per Square Inch p	h	$\frac{p\,(v-v_1)}{J}$	$h-\frac{p\,(v-v_1)}{J}$	cub. ft. v	cub. ft. v_1	$\frac{1}{v}$	w_1	
— 40	420.66	1539.90	10.69	579.67	48.23	531.44	24.388	.02348	.0410	42.589	
— 35	425.66	1773.43	12.31	576.68	48.48	528.21	21.321	.02362	.0469	42.337	
— 30	430.66	2035.69	14.13	573.69	48.77	524.92	18.693	.02374	.0535	42.123	
— 25	435.66	2329.34	16.17	570.68	49.06	521.62	16.446	.02389	.0608	41.858	1.47
— 20	440.66	2657.23	18.45	567.67	49.38	518.29	14.507	.02403	.0689	41.615	3.75
— 15	445.66	3022.31	20.99	564.64	49.67	514.97	12.834	.02417	.0779	41.374	6.29
— 10	450.66	3427.75	23.80	561.61	50.05	511.62	11.385	.02431	.0878	41.135	9.10
— 5	455.66	3876.85	26.92	558.56	50.31	508.25	10.125	.02445	.0988	40.9	12.22
+ 0	460.66	4373.10	30.37	555.50	50.68	504.82	9.028	.02461	.1107	40.65	15.67
+ 5	465.66	4920.11	34.16	552.43	50.84	501.59	8.070	.02475	.1240	40.404	19.46
+ 10	470.66	5521.71	38.34	549.35	51.13	498.22	7.229	.02490	.1383	40.16	23.64
+ 15	475.66	6182.00	42.94	546.26	51.33	494.93	6.491	.02505	.1541	39.92	28.24
+ 20	480.66	6904.68	47.95	543.15	51.61	491.54	5.843	.02520	.1711	39.68	33.25
+ 25	485.66	7694.52	53.43	540.03	51.80	488.23	5.270	.02536	.1897	39.432	38.73
+ 30	490.66	8555.74	59.42	536.91	52.01	484.91	4.763	.02551	.2099	39.20	44.72
+ 35	495.66	9493.07	65.92	533.78	52.22	481.56	4.314	.02568	.2318	38.94	51.22
+ 40	500.66	10511.16	72.99	530.63	52.42	478.21	3.915	.02585	.2554	38.684	58.29
+ 45	505.66	11615.12	80.66	527.47	52.62	474.85	3.559	.02600	.2809	38.461	65.96
+ 50	510.66	12809.91	88.96	524.30	52.82	471.48	3.242	.02616	.3084	38.226	74.26
+ 55	515.66	14100.74	97.92	521.12	53.01	468.11	2.958	.02632	.3380	37.994	83.22
+ 60	520.66	15493.09	107.59	517.93	53.21	464.72	2.705	.02651	.3697	37.736	92.89
+ 65	525.66	16992.50	118.03	514.73	53.38	461.35	2.476	.02668	.4039	37.481	103.33
+ 70	530.66	18604.53	129.19	511.52	53.57	457.85	2.272	.02686	.4401	37.23	114.49
+ 75	535.66	20335.16	141.22	508.29	53.76	454.53	2.087	.02703	.4791	36.995	126.52
+ 80	540.66	22190.15	154.10	505.05	53.96	450.70	1.921	.02721	.5205	36.751	139.40
+ 85	545.66	24175.61	167.88	501.81	54.15	447.66	1.770	.02739	.5649	36.509	153.18
+ 90	550.66	26297.88	182.62	498.55	54.28	443.83	1.634	.02758	.6120	36.258	167.92
+ 95	555.66	28563.00	198.35	495.29	54.41	440.88	1.510	.02776	.6622	36.023	183.65
+100	560.66	30977.78	215.12	492.01	54.54	436.96	1.398	.02795	.7153	35.778	200.42

Properties of Saturated Ammonia Gas

De Volson Wood and Geo. Davidson

Gauge Pressure Pounds per Square Inch	Absolute Pressure, Pounds per Square Inch	Temperature Degrees F.	Absolute Temperature Degrees F.	Latent Heat of Evaporation in Thermal Units	Volume of 1 Pound Vapor in Cubic Feet	Weight of 1 Cubic Foot of Vapor in Pounds	Volume of 1 Pound of Liquid in Cubic Feet	Weight of 1 Cubic Foot of Liquid in Pounds
—4.01	10.69	—40	420.66	579.67	24.38	.0410	.0234	42.589
—2.39	12.31	—35	425.66	576.68	21.32	.0469	.0236	42.337
—0.57	14.13	—30	430.66	573.69	18.69	.0535	.0237	42.123
+1.47	16.17	—25	435.66	570.68	16.44	.0608	.0238	41.858
3.75	18.45	—20	440.66	567.67	14.51	.0690	.0240	41.615
6.29	20.99	—15	445.66	564.64	12.83	.0779	.0241	41.374
9.10	23.80	—10	450.66	561.61	11.38	.0878	.0243	41.135
12.22	26.92	— 5	455.66	558.56	10.12	.0988	.0244	40.900
15.67	30.37	0	460.66	555.50	9.03	.1107	.0246	40.650
19.46	34.16	+ 5	465.66	552.43	8.07	.1240	.0247	40.404
23.64	38.34	10	470.66	549.35	7.23	.1383	.0249	40.160
28.24	42.94	15	475.66	546.26	6.49	.1541	.0250	39.920
33.25	47.95	20	480.66	543.15	5.84	.1711	.0252	39.682
38.73	53.43	25	485.66	540.03	5.27	.1897	.0253	39.432
44.72	59.42	30	490.66	536.91	4.76	.2099	.0255	39.200
51.22	65.92	35	495.66	533.78	4.31	.2318	.0256	38.940
58.29	72.99	40	500.66	530.63	3.91	.2554	.0258	38.684
65.96	80.66	45	505.66	527.47	3.56	.2809	.0260	38.461
74.26	88.96	50	510.66	524.30	3.24	.3084	.0261	38.226
83.22	97.92	55	515.66	521.12	2.96	.3380	.0263	37.994
92.89	107.59	60	520.66	517.93	2.70	.3697	.0265	37.736
103.33	118.03	65	525.66	514.73	2.48	.4039	.0266	37.481
114.49	129.19	70	530.66	511.52	2.27	.4401	.0268	37.230
126.52	141.22	75	535.66	508.29	2.09	.4791	.0270	36.995
139.40	154.10	80	540.66	505.05	1.92	.5205	.0272	36.751
153.18	167.88	85	545.66	501.81	1.77	.5649	.0273	36.509
167.92	182.62	90	550.66	498.55	1.64	.6120	.0275	36.258
183.65	198.35	95	555.66	495.29	1.51	.6622	.0277	36.023
200.42	215.12	100	560.66	492.01	1.39	.7153	.0279	35.778
218.28	232.98	105	565.66	488.72	1.289	.7757	.0281	
237.27	251.97	110	570.66	485.42	1.203	.8312	.0283	
258.7	272.14	115	575.66	482.41	1.121	.8912	.0285	
275.79	293.49	120	580.66	478.79	1.041	.9608	.0287	
301.46	316.16	125	585.66	475.45	.9699	1.0310	.0289	
325.72	340.42	130	590.66	472.11	.9051	1.1048	.0291	
350.46	365.16	135	595.66	468.75	.8457	1.1824	.0293	
377.52	392.22	140	600.66	465.39	.7910	1.2642	.0295	
405.79	420.49	145	605.66	462.01	.7408	1.3497	.0297	
435.5	450.20	150	610.66	458.62	.6946	1.4396	.0299	
466.84	481.54	155	615.66	455.22	.6511	1.5358	.0302	
499.70	514.50	160	620.66	451.81	.6128	1.6318	.0304	
534.34	549.04	165	625.66	448.39	.5765	1.7344	.0306	

One atmosphere in this table is equal to a pressure of a column of mercury 29.9 inches high.
Specific heat of ammonia gas and vapor at constant pressure . . . = 0.508
The same at constant volume . . . . = 0.3913
Weight of 1 cubic foot liquid ammonia at 32 degrees Fahr. . . . . =39.108 pounds
Volume of 1 pound liquid ammonia at 32 degrees Fahr. . . . . . = 0.02557 cu. ft.
Specific heat of liquid ammonia . . . . =1.01235+0.008378 t, [2]

TABLE 2.

DESCRIPTION OF INSTALLATION TESTED.

The installation tested consisted of a standard 10 ton vertical single acting ice making and refrigerating machine, manufactured by the York Manufacturing Company of York Pennsylvania, U.S.A. This machine was erected in the Mechanical Engineering Laboratory of the University of Illinois in December 1905. Plates 1-14 and figures 1-7 illustrate the general features of the installation. The two vertical single acting false, or safty head compressors are operated by an engine fitted with a Corliss valve gear. Each compressor has a 7 $\frac{1}{2}$ inch bore and a 10 inch stroke and the steam cylinder has a 11 $\frac{1}{2}$ inch bore and a 10 inch stroke. The rated capacity of the machine is 10 tons of refrigeration per 24 hours upon a basis of 15.67 pounds back pressure, 185 pounds condensing pressure and 95 revolutions per minute. The capacities of the machine at a speed of 95 revolutions per minute are given in table 3.

Condenser Gauge Press. and Corresponding Temperature	Suction Gauge Pressure and Corresponding Temperature											
	5 lb = −17.5° F		10 lb = −8.5° F		15.67 lb = 0° F.		20 lb = 5.7° F,		25 lb = 11.5° F.		30 lb = 16.8° F	
	Capacity Tons, Refrig.	Horse Power, Engine	Capacity Tons, Refrig.	Horse Power, Engine	Capacity Tons, Refrig.	Horse Power, Engine	Capacity Tons, Refrig.	Horse Power, Engine	Capacity Tons, Refrig.	Horse Power, Engine	Capacity Tons, Refrig.	Horse Power, Engine
145 lb = 82° F	6.6	12.7	8.5	13.9	10.7	14.9	12.4	15.4	14.3	15.8	16.3	16.1
165 lb = 89° F	6.4	13.7	8.2	14.9	10 3	16.2	12.	16.8	13.9	17.4	15.8	17.8
185 lb = 95.5° F	6.2	14.6	8.	16.	10.	17.3	11.6	18.1	13.4	18.8	15.3	19.4
205 lb = 101.4° F	6.	15.3	7.7	16.9	9.7	18.5	11.2	19.3	13.	20.2	14.8	20.9

TABLE 3.

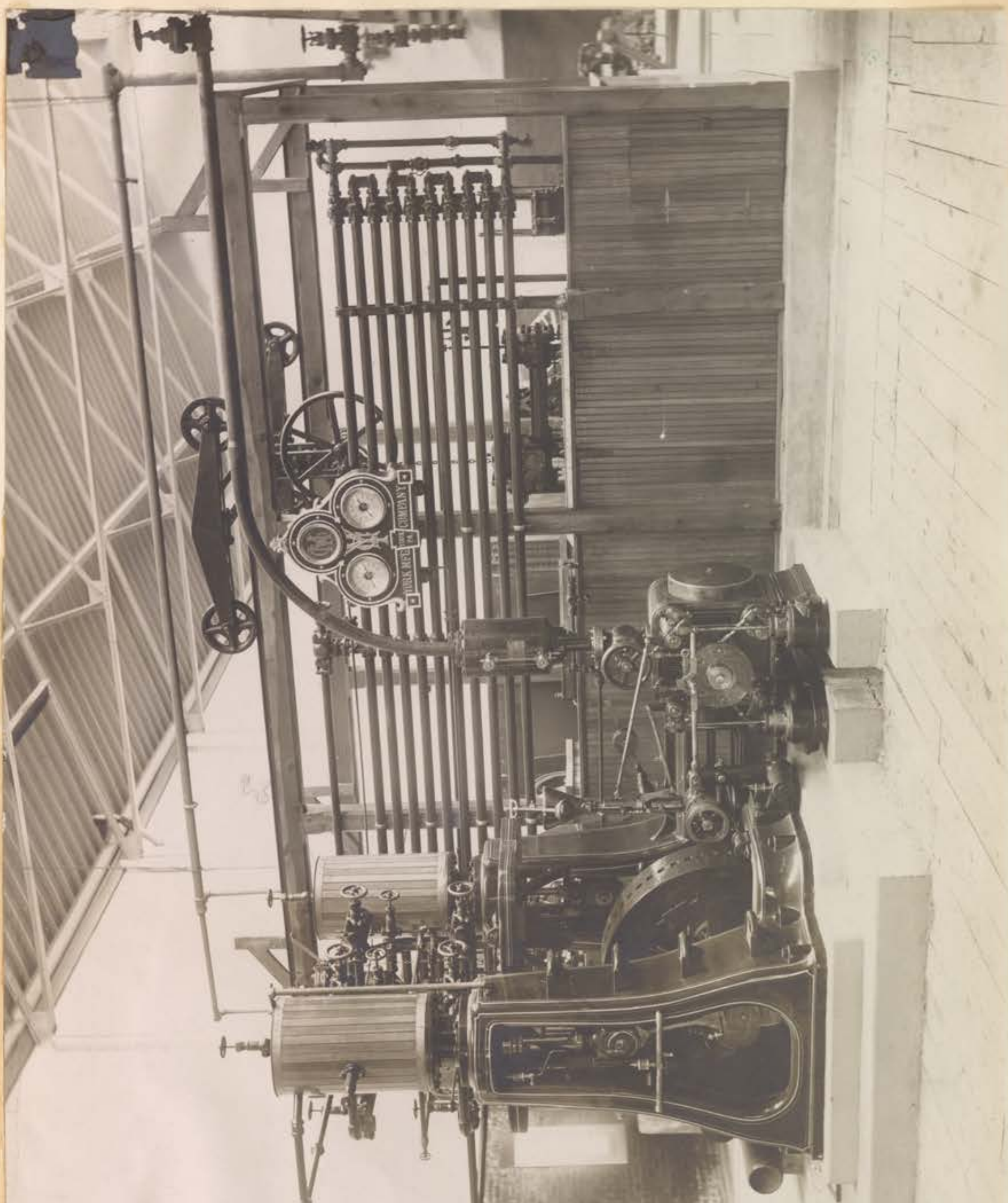
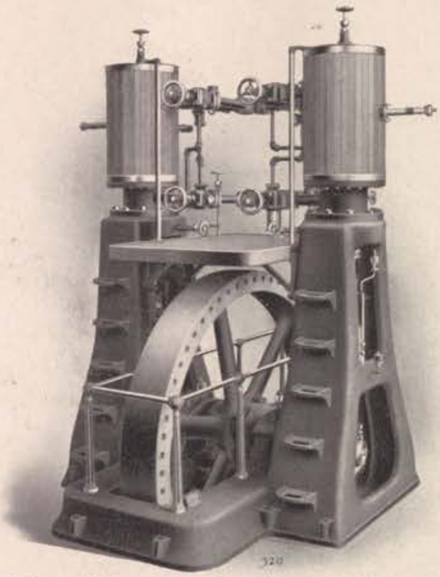
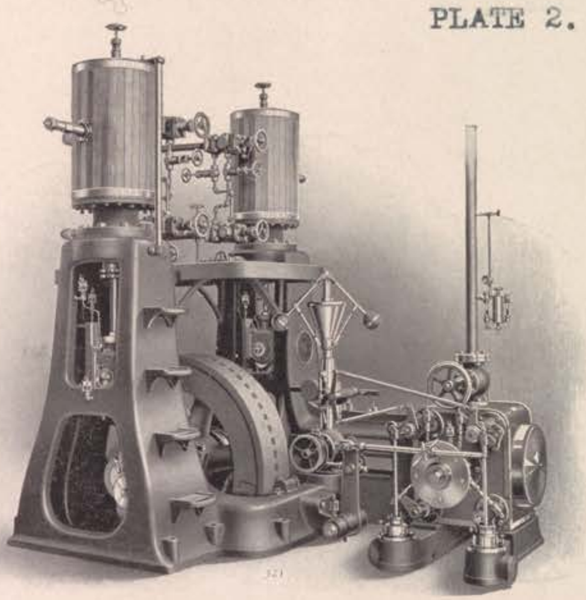


PLATE 1.

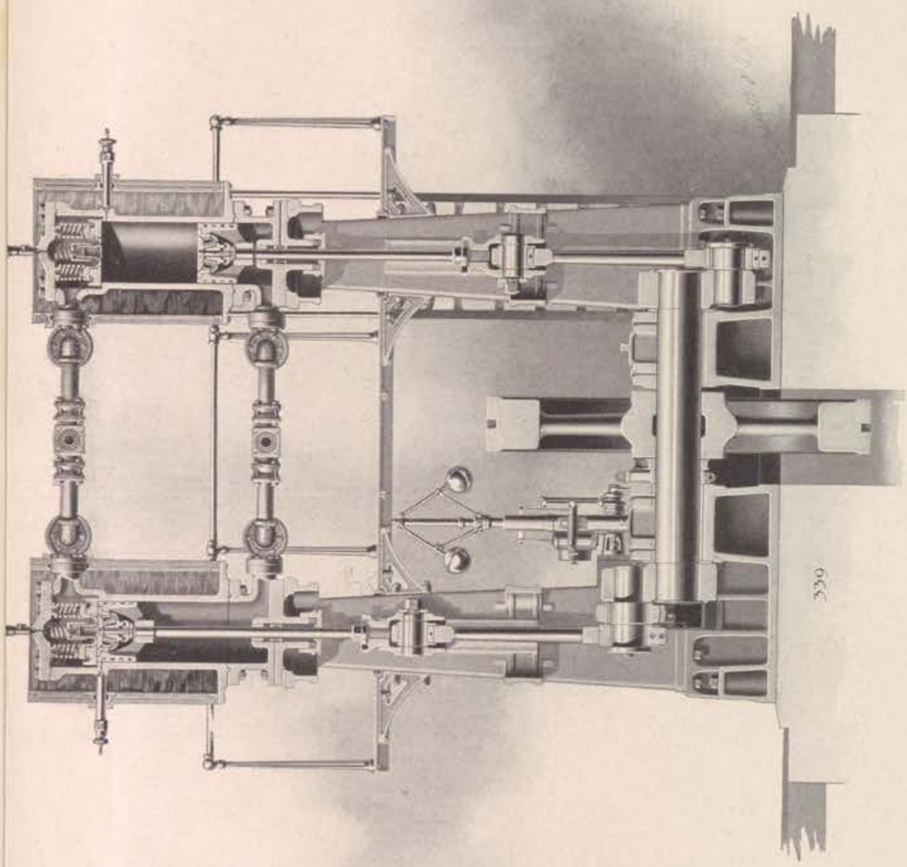


Ten-Ton Belt Driven Machine
Figure A.

PLATE 2.



Ten Ton Corliss Engine Driven Machine.
Figure B.



Cross Sectional View of Machine

PLATE 3.

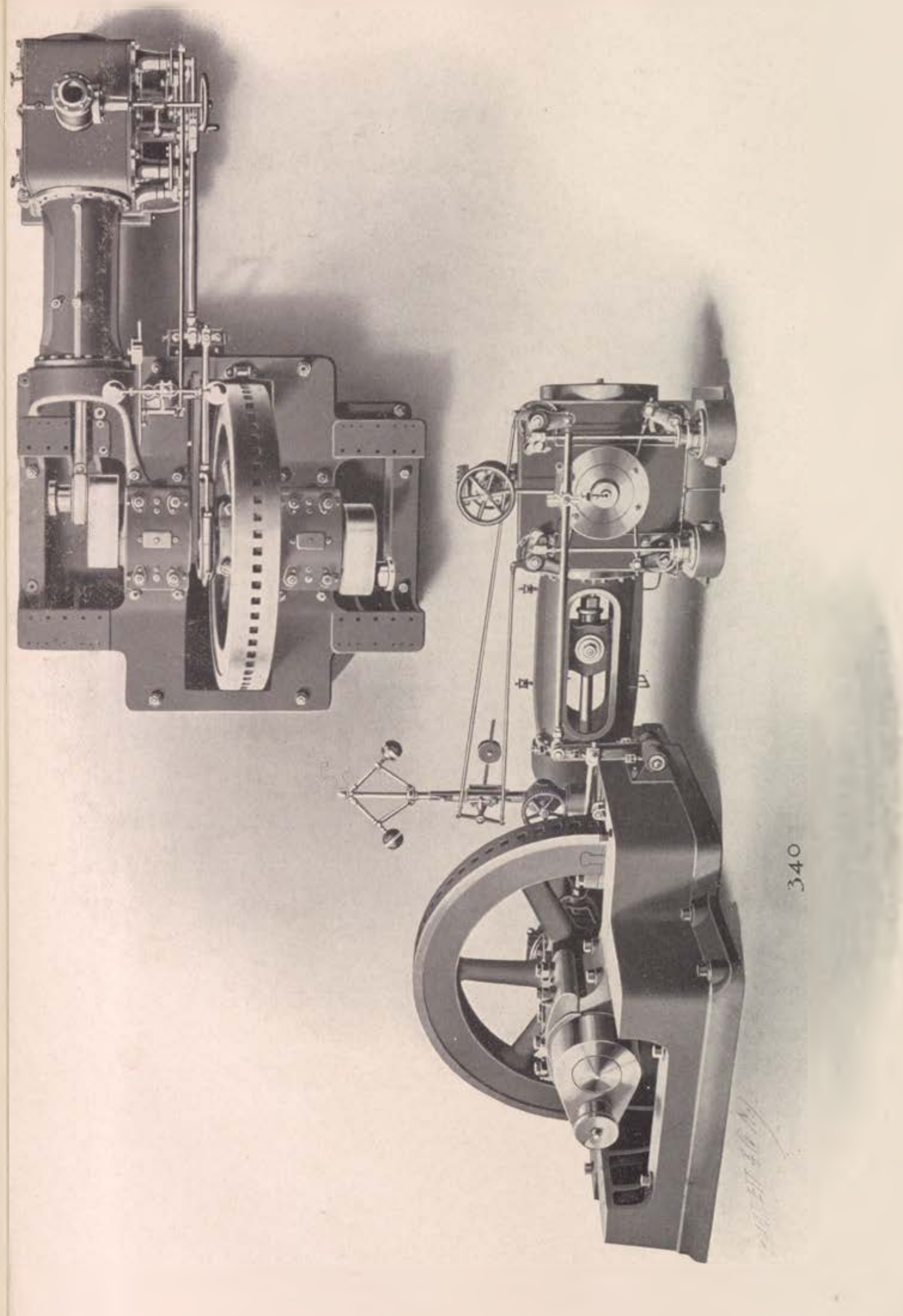


PLATE 4.

Details of Compressor - 10 Ton Machine.

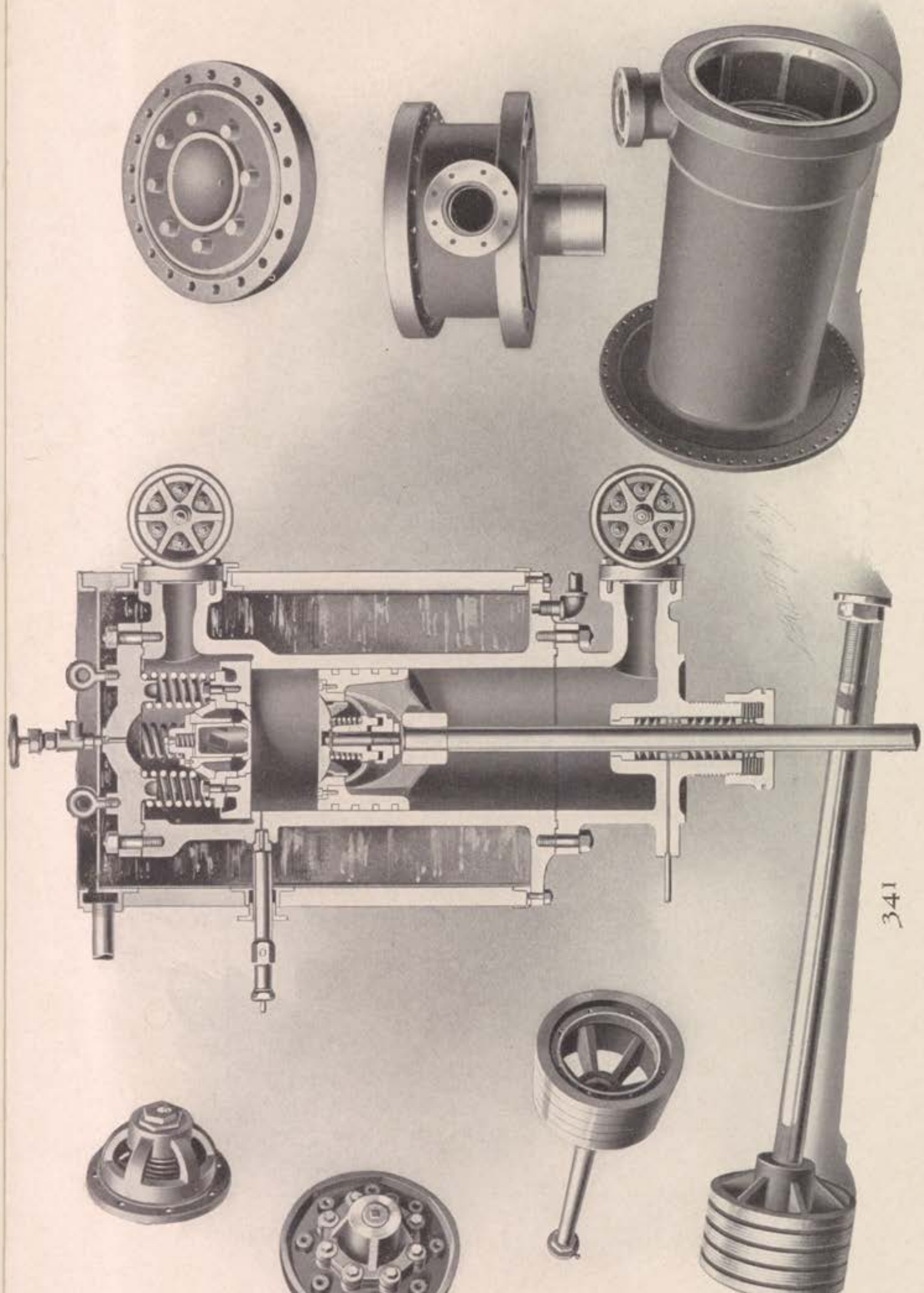


PLATE 5.

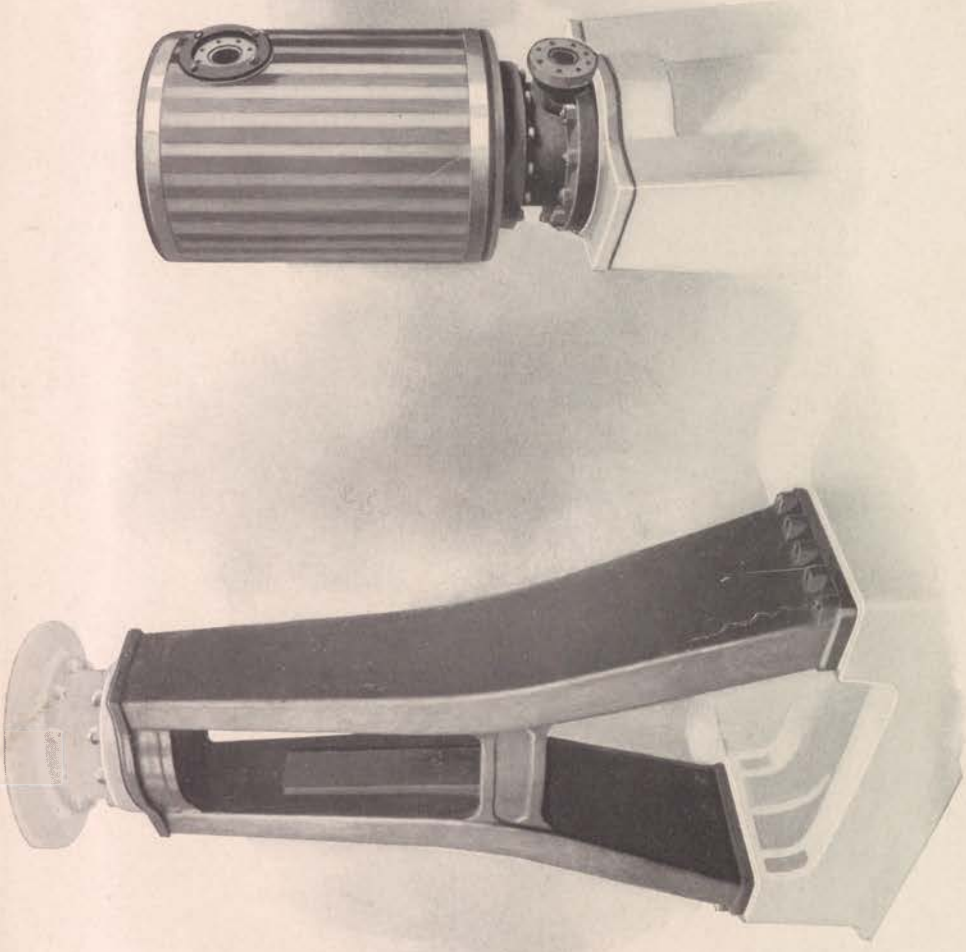
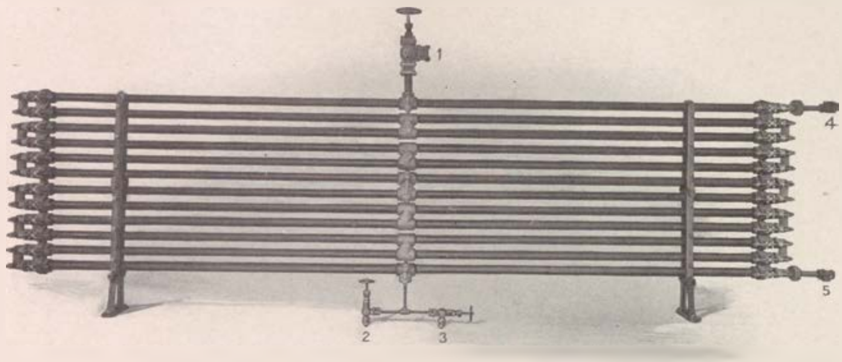


PLATE 6.

Double Pipe Ammonia Condenser

"W." & "C." Type



Capacity Tons Refrigeration	No. of Pipes in Height	Length Over All	Shipping Weight	Price
2	2	17'6"	400	$60.00
4	4	17'6"	750	100.00
6	6	17'6"	1100	140.00
8	8	17'6"	1375	180.00
10	10	17'6"	1650	220.00
12½	12	17'6"	1900	260.00
15	14	17'6"	2150	300.00

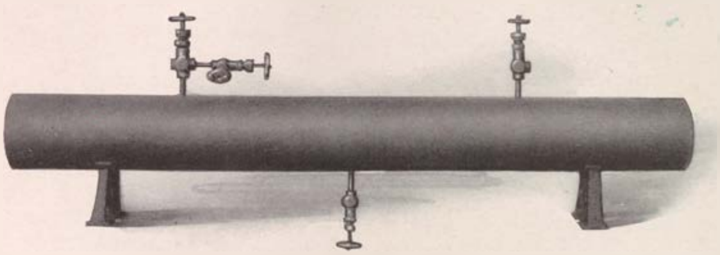
The above condensers are made of 1¼ and 2-inch selected ammonia pipe.

When more than one section is furnished the necessary ammonia and water headers are included in price quoted. Above capacities are based on 70 degrees cooling water.

1. Gas inlet.
2. Liquid outlet.
3. Pumping out connection.
4. Water outlet.
5. Water inlet.

PLATE 7.

Ammonia Receivers



Diam. inches	Length, feet	Number	Weight	Price
12	4	1972	250	$65.00
12	5	1973	300	70.00
12	6	1974	350	75.00
16	6	1975	450	95.00
16	7	1976	500	105.00
20	6	1977	600	125.00
20	7	1978	675	135.00
20	8	1979	750	145.00
24	7	1980	900	165.00
24	8	1981	1000	178.00
24	9	1982	1125	190.00
24	10	1983	1250	205.00
24	11	1984	1400	220.00
24	16	1985	2000	300.00

Our ammonia receivers are made of best flanged steel, with welded shell and heads, and are guaranteed to stand a pressure of 500 pounds.

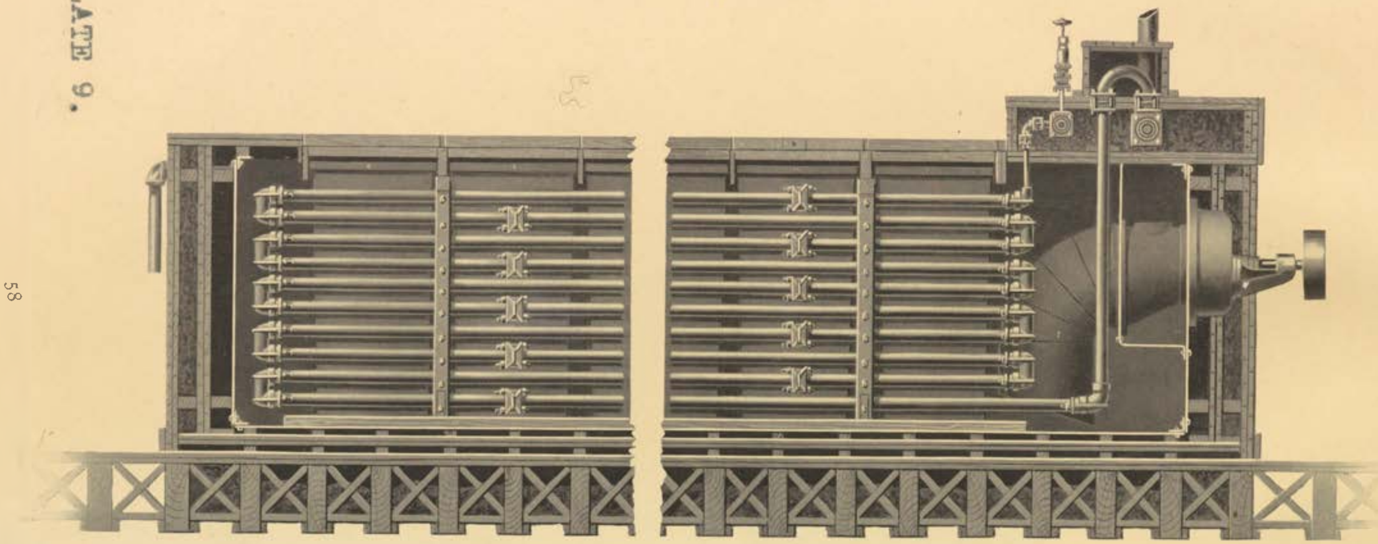
Above prices are for horizontal receivers and include stands, also inlet, outlet, drain and charging valves. We also furnish receivers of the vertical style at a slight increase in price to cover the additional cost of vertical stands. (See price list for Stands, page 65.)

In ordering, specify size of inlet and outlet valves.

PLATE 8.

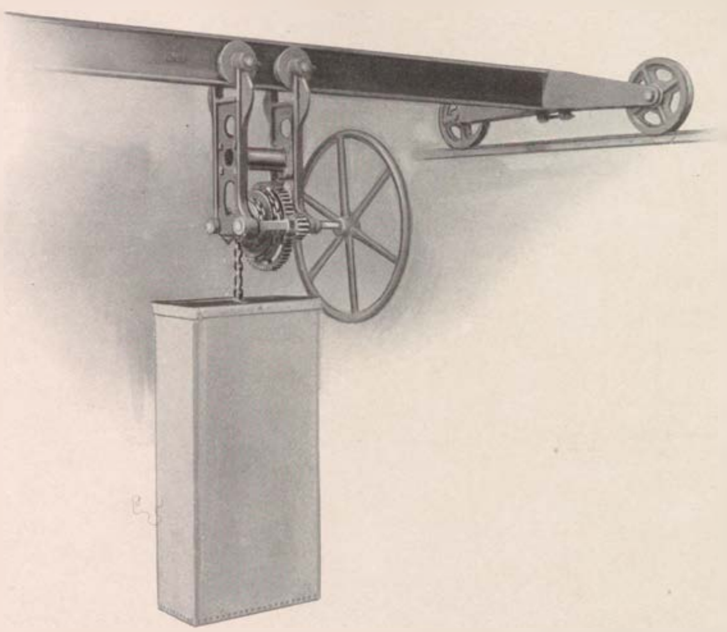
PLATE 9.

Freezing Tank



STANDARD FREEZING TANK

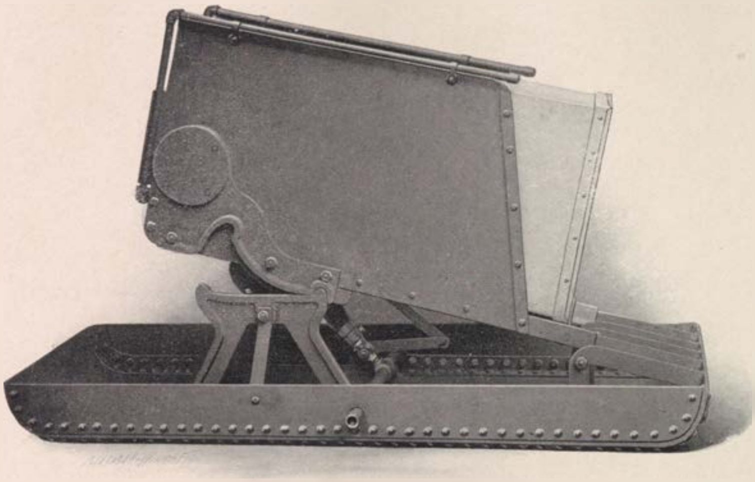
Hand Crane and Hoist



The above cut illustrates our standard hand hoist for handling ice cans. The bridge is made of steel I-beams. It is of very substantial construction throughout, and is very light in weight and very easily handled by one man. We make them to lift either one or two cans at a time. Prices on application.

(PLATE 11 OVER) PLATE 10.

Ice Dumps



Size of Can	Weight	Price
50-pound	325 pounds	$95.00
100-pound	350 pounds	115.00
200-pound	500 pounds	135.00
300-pound	700 pounds	150.00
400-pound	850 pounds	175.00

These dumps, of the automatic rocking type, are made entirely of iron, and are of very substantial construction. They are provided with iron pans to carry away waste water, the loss of which is reduced to a minimum by an attachment that stops the flow of the thawing water as the ice emerges from the can.

PLATE 12.

Ice Cans

Weight of Cake of Ice	Inside Dimensions			Length Over All	Thickness of Material U. S. Standard Gauge	
	Top	Bottom	Length		Sides	Bottom
50 lbs.	8 x 8	7½ x 7½	31	32	No. 16	No. 16
100 lbs.	8 x 16	7¼ x 15¼	31	32	No. 16	No. 16
200 lbs.	11½ x 22½	10½ x 21½	31	32	No. 16	No. 16
300 lbs.	11½ x 22½	10½ x 21½	44	45	No. 16	No. 16
400 lbs.	11½ x 22½	10½ x 21½	57	58	No. 14	No. 14

The above sizes are in accordance with the standard adopted by the Ice Machine Builders Association of the United States. These sizes are carried in stock, and prices will be quoted on application.

All other sizes are regarded as special, will be built only on order, and will be subject to special price.

Cans are made throughout of galvanized material, well riveted and soldered, and guaranteed tight. Cans made of No. 16 gauge material will be turned over top and bottom. The 200, 300 and 400-pound cans have ¼ x 2-inch galvanized bands around top. Small sizes have ¼ x 1¼-inch bands; ⅝-inch lifting holes are punched through bands. Prices quoted on application.

PLATE 13.

Plan and elevation of ten-ton machine with simple engine.

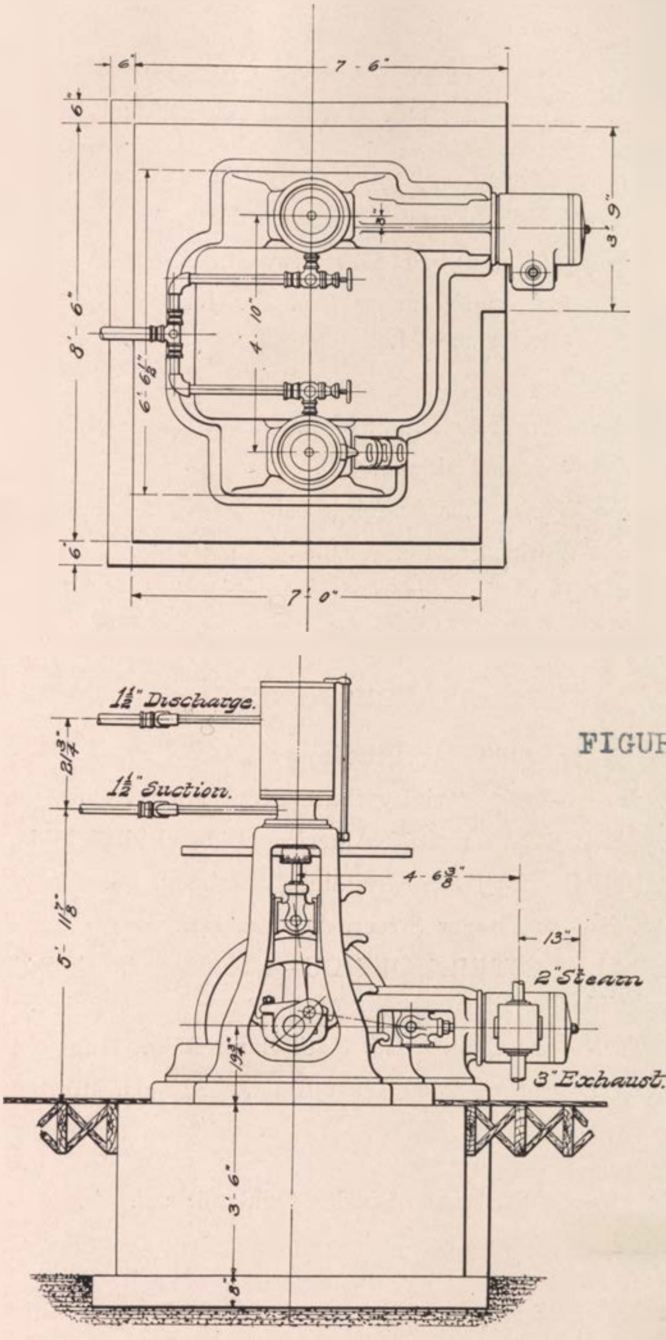
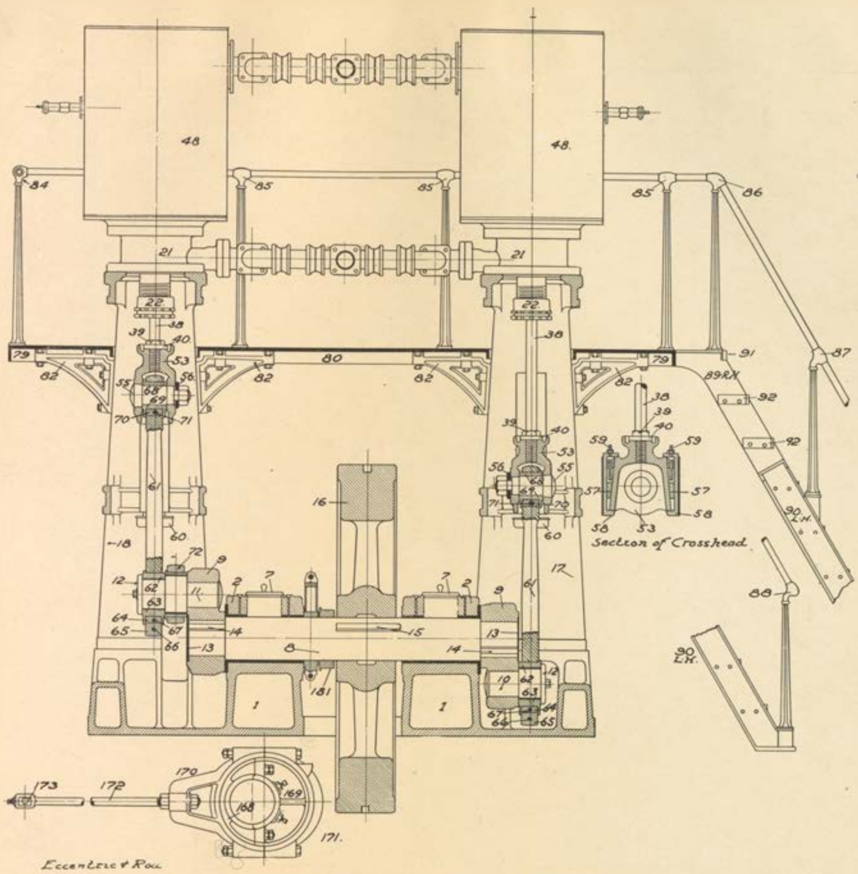


FIGURE 2.

Total height of machine, 8′-6¾″

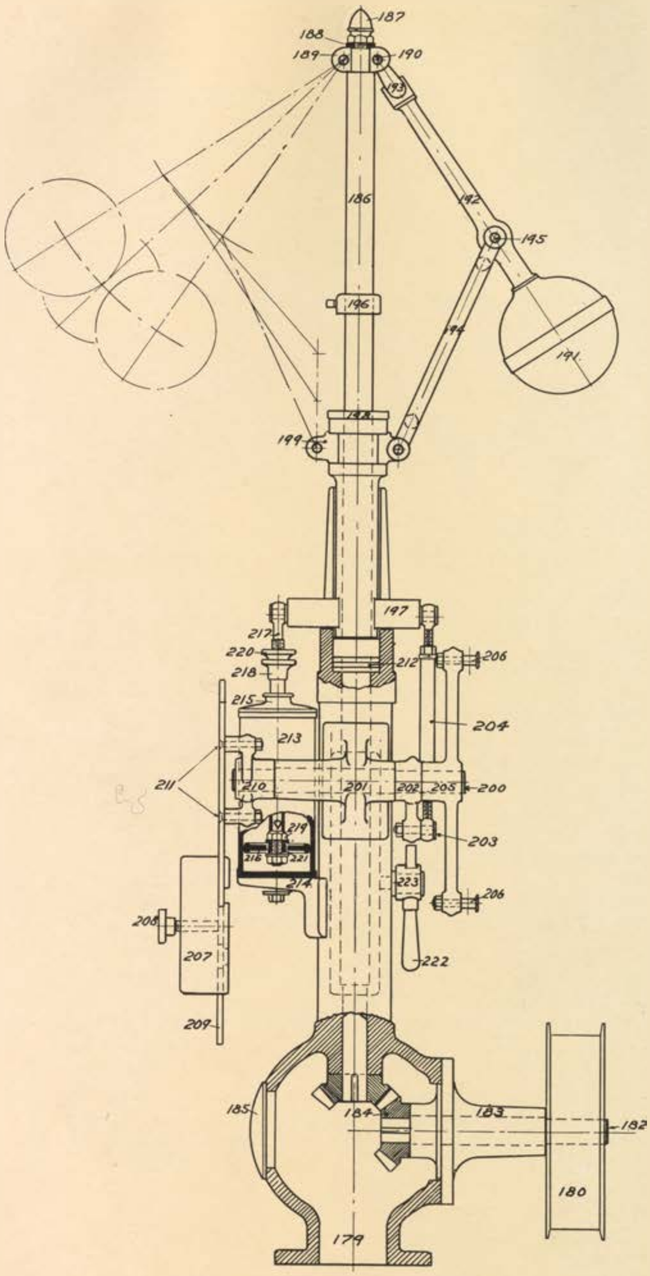


SECTION THROUGH CRANK SHAFT

1 Bed Plate
2 Pedestal Cap
7 Pedestal Cap—Hand-hole Cover
8 Crank Shaft
9 Crank Disk
10 Crank Pin for Compressor
11 Crank Pin for Engine
12 Crank Pin Cap
13 Crank Brass Plate
14 Crank Key
15 Fly Wheel Key
16 Fly Wheel
17 Housing—Without opening for Rod
18 Housing—With opening for Rod
21 Compressor Lower Head
22 Compressor Stuffing-box Nut
38 Compressor Piston Rod
39 Compressor Piston Rod Lock Nut
40 Compressor Piston Rod Lock Collar
48 Water Jacket
53 Compressor Cross-head
55 Cross-head Pin and Nut
56 Cross-head Pin Washer
57 Cross-head Wedge
58 Cross-head Shoe
59 Cross-head Adjusting Bolt
60 Cross-head Drip Pan
61 Compressor Connecting Rod
62 Crank End Box
63 Crank End Box Tapered
64 Crank End Wedge
65 Crank End Tongue
66 Crank End Tongue Bolt
67 Crank End Wedge Adjusting Bolt
68 Cross-head End Box
69 Cross-head End Box Tapered
70 Cross-head End Wedge
71 Cross-head End Wedge Adjusting Bolt
72 Engine Connecting Rod (See Page 4 for Boxes)
79 Gallery Plate—End
80 Gallery Plate—Center
82 Gallery Bracket
84 Gallery Post—Corner
85 Gallery Post—Straightway
86 Gallery Post—At top of Stairs
87 Gallery Post—Intermediate Stair
88 Gallery Post—Bottom Stair
89 Gallery Stair Horse—R. H.
90 Gallery Stair Horse—L. H.
91 Gallery Stair Top Step
92 Gallery Stair Steps
168 Eccentric Hub—Small Half
169 Eccentric Hub—Large Half
170 Eccentric Strap—Rod End
171 Eccentric Strap—Back End
172 Eccentric Rod
173 Eccentric Rod Box
181 Governor Pulley (Give Diameter)

(TABLF 4 OVER)

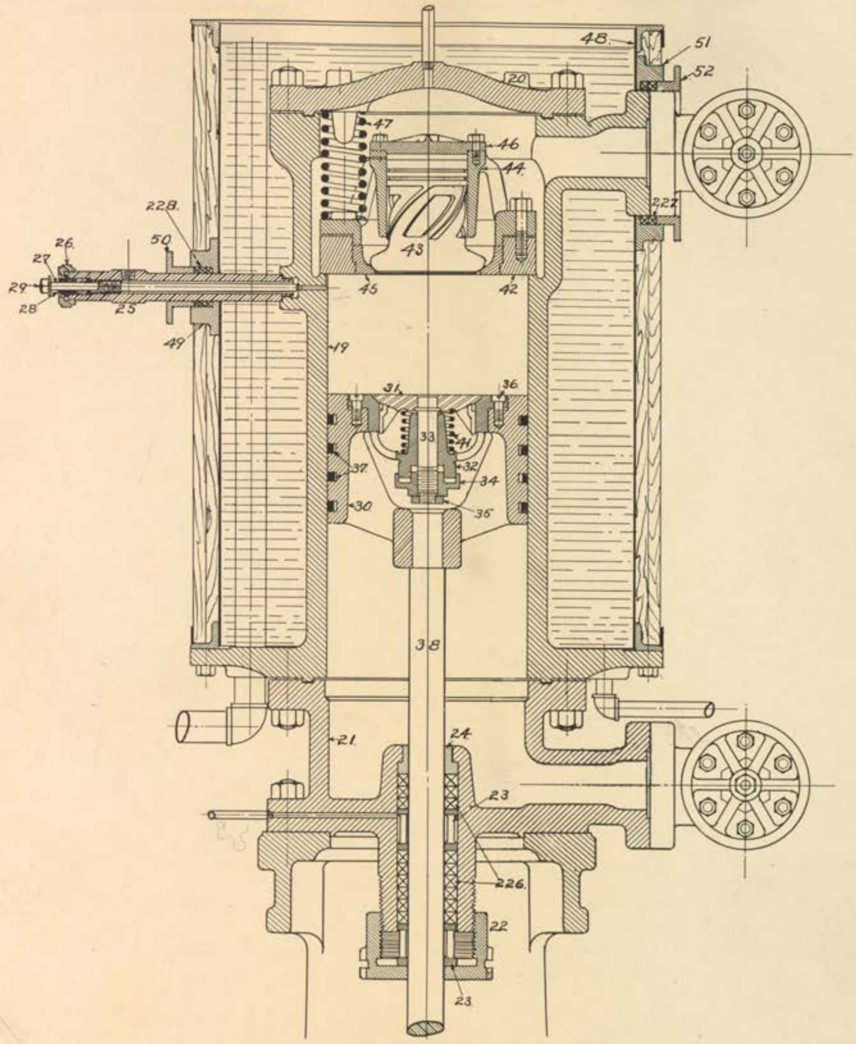
FIGURE 3.



STANDARD CORLISS GOVERNOR

(FIGURE 5 OVER)

FIGURE 4.



SECTION OF COMPRESSOR

19 Compressor Barrel
20 Compressor Top Head
21 Compressor Lower Head
22 Compressor Stuffing-box Nut
23 Compressor Stuffing-box Lantern Gland
24 Compressor Stuffing-box Bushing
25 Indicator Valve Body
26 Indicator Valve Packing Nut
27 Indicator Valve Stem
28 Indicator Valve Stem Gland
29 Indicator Valve Stem Wrench Nut
30 Ammonia Piston
31 Suction Valve
32 Suction Valve Cage
33 Suction Valve Stem
34 Suction Valve Cushion Nut
35 Suction Valve Lock Nut
36 Round Head Screws for Cage
37 Snap Rings
38 Piston Rod
41 Suction Spring
42 Safety Head
43 Discharge Valve
44 Discharge Valve Cage
45 Discharge Valve Seat
46 Discharge Valve Cap
47 Springs for Safety Head (Give Diameter and Length)
48 Water Jacket Body
49 Indicator Valve Stuffing-box
50 Indicator Valve Stuffing-box Gland
51 Stuffing-box for Discharge Nozzle
52 Stuffing-box Gland Discharge Nozzle
226 Packing for Ammonia Piston Rod
227 Packing for Water Jacket Discharge Nozzle
228 Packing for Water Jacket Indicator Nozzle

(FIGURE 7 OVER)

FIGURE 6.

The machine has a rated ice making capacity of 6 tons of ice per 24 hours, but is equipped with a brine tank which accomodates expansion coils and cans enough for but 1.5 tons per 24 hours.

ENGINE: The engine operating the compressors is illustrated by Plates 1,2, and 4 and by Fig. 5 and 7. The valve gear is of the Corliss type, with its parts arranged for adjustment when the engine is in motion. The wrist plate is provided with a disconnecting device, so that the gearing may be operated by hand. The governor is of the Corliss fly ball type connected to the crank shaft by belt and arranged to control the machine with a variation of forty revolutions while running. A safty device is attached to the valve gear and governor, operating automatically to stop the engine in event of the governor belt breaking. The connecting rods are provided with wedge adjustments for taking up wear and the cross head ends of the rods are fitted with brass boxes bored and scraped to fit the pins.

COMPRESSORS. The compressor cylinders are two in number working alternately and connected with the gas supply in parallel. Plates 1,2,3,5 and 6 and Fig. 2,3 and 5 illustrate the general arrangement and design. The gas enters at the bottom of the compressor(see Fig.6) and passes up through the suction valve in the piston. It is compressed and driven out through the discharge valve in the center of the safty head by the up stroke of the piston. The piston and the bottom of the safty head are faced off square so that by close contact at the end of each stroke, the clearance is reduced to a minimum. The safty head is a device provided so as to prevent the destruction of the compressor in the event of accidental breaking of valves or in case of an over charge of liquid ammonia. The safty head rises and permits the obstruction to pass through or keeps on rising until the engine can be stopped. A water jacket encases the compressor cylinders. The water entering at the bottom circulates around the cylinder walls and up over the top cover where it overflows.

CONDENSER : The condenser is similar to the one shown in Plate 7 and is situated on the top of the brine tank as shown in Plate 1. Plate 2 shows the oil separator which is situated in the pipe line leading to the condenser.

AMMONIA RESERVOIR : The ammonia reservoir is shown in Plate 8 and is situated at the rear of the freezing tank shown in Plate 1.

EXPANSION VALVE : The expansion valve is situated in the ammonia line just after it leaves the ammonia reservoir and consists of a valve which controls the expansion by the adjustment of a tapered needle.

FREEZING TANK AND EXPANSION COIL: Plate 9 illustrates the construction of the freezing tank equipped with the expansion system of evaporating coils. The ammonia is expanded into headers connected at the top of the evaporating coils, the return being connected from the bottom of the coils to the suction header. The evaporating coils are made of $1\frac{1}{4}$ inch wrought iron ammonia pipe connected with the proper stands, valves, headers, and fittings. The tank is made of steel $\frac{1}{4}$ inch thick and is surrounded by a heavily insulated hard wood frame work.

TRAVELING CRANE etc. Plate 10 illustrates the general features of the traveling crane used for lifting the cans from the tank and conveying them to the automatic thawing and dumping apparatus shown in Plate 2. Plate 13 explains the construction of the ice can, each of which has a capacity of 100 pounds.

DISCUSSION OF CONDITIONS OF PRACTICAL OPERATION.

DESCRIPTION OF CYCLE. The engine operating the compressors draws the gas from the evaporating coils into a suction header contained in the brine tank, and finally through the suction pipe into the suction side of the compressor. Having passed through the valve in the piston upon the down stroke thereof a cylinderful is compressed upon the return stroke and is discharged into the condenser. Here it is liquified due to the abstraction of heat by the cooling water and is collected in the ammonia reservoir. Passing through the expansion valve the liquid becomes a gas with more or less rapidity in the expansion coils, expanding to this condition due to the reduced pressure caused by the suction of the compressors, and absorbing a quantity of heat which it renders latent. This heat is abstracted from the brine which is circulated,by means of a steam pump, around the expansion coils, the brine in turn abstracting heat from the water in the ice cans.

CHARGING. To charge the system with anhydrous ammonia the compressors are worked so as to discharge the air through special valves. The ammonia is then drawn into the system gradually about half of the full charge at first and the rest while permitting the air still remaining to escape through the purge cocks with as little loss of the gas as possible. An additional amount is put in once or twice a day until the air is entirely displaced.

STARTING AND REGULATION : To start the machine the expansion valve is first opened and the engine started. The temperature at the delivery valve is then read and the valve of the compressor adjusted until the temperature becomes the same as that of the cooling water leaving the condenser. Every stroke of the piston should be clearly marked by corresponding vibrations of the hands of the condenser and suction gages. The frost on the ammonia pipes leading to and from the expansion coils should be about the same. The liquid ammonia should pass through the expansion valve in a continuous stream. The temperature of the ammonia in the condenser should be about 15° higher than that of the cooling water running from the condenser overflow. The temperature in the expansion coils should be about 15° lower than the actual temperature of the brine or other refrigerate . If any air is present in the system in quantities sufficient to interfere with economical operation it will be indicated by a whistling noise in the pipes, a rise in the condenser pressure, and an intermittent discharge of liquid ammonia through the expansion valve which can in some cases be distinctly heard. In this case the system should be delivered of the trouble by means of the purge cocks. The air gets into the system through the stuffing boxes and piping connections. The presence of oil or water in the system is another disadvantage in successful operation. It is indicated by perciptible hammering within the compressor cylinders.

The stuffing boxes of the compressors require an ample supply of high grade mineral oil, because of the cutting action of the hot ammonia gas upon even the best of packing. Animal and vegetable oils saponify when in contact with ammonia and when used cause considerable trouble.

In successful operation the expansion valve and the valve at the common discharge of the cylinders require special attention for the reason that it is necessary to maintain the suction and the condenser pressures constant.

The amount of cylinder jacket water should be about 15 gallon per hour per ton of refrigeration per day of 24 hours for condenser pressures of about 100 pounds gage. For pressures of about 150 pounds the amount should be about 50 gallons per hour. Good practice advocates as large an amount of cylinder water as possible if it is not wasted.

The quantity and temperature of cooling water in the condenser should be determined by a consideration of the fact that the lower the temperature to which the condensed ammonia is cooled, the less will be the pressure against which the compressors have to pump. This tends toward economy of operation, due to the saving of power and fuel and general depreciation of the machinery. The amount of condensing water required depends upon the temperature at which it is discharged from the condenser. If run to condenser at 60° F. and discharged at 90° F. the amount required will be about 1 gallon per minute per ton of refrigerating capacity per 24 hours. If discharged at 75°, inlet temperature the same as before, the amount required will be about 2.5 gallons per minute, which results in a reduction in the condenser pressure of about 40 pounds. Where the cost of water is of some consideration, the practice of cooling the ammonia below 60° F. during the winter, and below 70° F. during the summer is questionable economy. Where the cost of water is excessive every attempt should be made to utilize it to the limit, by the use of the cooling towers or other cooling apparatus.

The required temperatures can be regulated either by running the machine at higher speeds, by increasing the back pressure, or by a combination of both methods. The back pressure may be regulated by the expansion valve.

WET AND DRY COMPRESSION.

The wet compression system of operating consists of expanding the liquid in the condenser to a relatively high back pressure thus increasing the expansion work and actually helping the compressor and increasing the efficiency accordingly. The vapor comes back to the cylinder, however, in a supersaturated condition with the results that the liquid part of the charge is evaporated during the compression stage. In the compressor the gas absorbs the required amount of heat and issues there from at a correspondingly low temperature, which means of course a smaller capacity for heat absorbtion later. In other words it is claimed by the advocates of this system, that less compressor work at the expense of capacity for heat absorbtion, gives a maximum refrigerating efficiency. The practice is highly objectionable however when a machine is run so wet that large quantities of liquid get into the cylinder, resulting,in 1st. a filling of the clearance space with liquid, 2nd. a possible lifting of the safty head at the expense of considerable energy and 3rd. a reexpansion of the liquid in the clearance space, thereby reducing the amount of the new charge of gas.

Dry compression involves an adjustment of the expansion valve so that all of the ammonia liquid admitted to the expansion coil will expand into a gas, which arrives at the compressor in saturated or dry condition. During compression the gas is superheated. Dry compression has the advantage that the maximum heat carrying capacity of the ammonia may be realized. But because of the higher temperature of the gas as it enters the condenser, the pressure required to liquify it is correspondingly higher. The larger amount of heat generated requires an excessive amount of cooling water and condenser equipment, and for this reason the so called dry compression machines are worked partially wet. It may be stated that in general it is supposed that the efficiencies of both types are about the same. The installation tested is designed to operate on a partially wet compression principle. There is considerable difference of opinion among authorities concerning the relative merits of the two systems.

SINGLE ACTING COMPRESSION : The York vertical ice and refrigerating machine of the smaller capacities are single acting and are with out question the most efficient type for the following reason. The single acting compressor has a peculiar advantage when working with anhydrous ammonia gas, owing to the fact that it carries only the lower pressure, of the expansion part of the machine on the stuffing box end. Consequently the stuffing box is not subjected to the higher pressure of the condenser at the termination of each stroke as is the case in double acting compression. On this account the chance of leakage is reduced to a mimimum. However it is obvious that double acting compression is advisable from an ecconomic stand point, because it handles twice the amount of gas at each revolution of the crank shaft.

In each type there is the same ammount of friction as far as moving parts are concerned. This is not inconsiderable and in the double acting type there is a considerable amount of extra friction because of working with a tighter gland.

BRINE.

In the manufacture of ice and in some cases of refrigeration, an indirect method of abstracting heat is employed. A second medium is used to freeze water or for other cooling purposes, where it is inconvenient to employ the ammonia directly. It must be one which can be circulated in the liquid form without freezing. The two most common media are the brines of sodium chloride and calcium chloride, the former being more extensively used on account of its cheapness. The latter however is preferable where low temperatures are desired and is gradually taking the place of the cheaper material. Table 9 gives the general properties of each kind of brine.

CAPACITY OF AMMONIA COMPRESSORS.

The refrigerating capacity of a compressor is dependent upon the number of pounds of gas it will handle in a given unit of time.The weight of ammonia gas handled depends upon the efficiency of the compressor and upon the suction pressure,or the pressure at which the gas is delivered into the compressor.

Since the weight of ammonia gas varies approximately as the absolute pressure,it follows that the refrigerating capacity ofa compressor varies with the absolute suction(or back)pressure;

Table of Chloride of Calcium Solution

Specific Gravity at 64 Degrees F.	Degree Beaume at 64 Degrees F.	Degree Salometer at 64 Degrees F.	Per Cent. of $CaCl_2$.	Freezing Point in Degrees F.	Ammonia Gauge Pressure Pounds per Square Inch
1.007	1	4	0.943	+31.20	46
1.014	2	8	1.886	+30.40	45
1.021	3	12	2.829	+29.60	44
1.028	4	16	3.772	+28.80	43
1.035	5	20	4.715	+28.00	42
1.043	6	24	5.658	+26.89	41
1.050	7	28	6.601	+25.78	40
1.058	8	32	7.544	+24.67	38
1.065	9	36	8.487	+23.56	37
1.073	10	40	9.430	+22.09	35.5
1.081	11	44	10.373	+20.62	34
1.089	12	48	11.316	+19.14	32.5
1.097	13	52	12.259	+17.67	30.5
1.105	14	56	13.202	+15.75	29
1.114	15	60	14.145	+13.82	27
1.112	16	64	15.088	+11.89	25
1.131	17	68	16.031	+ 9.96	23.5
1.140	18	72	16.974	+ 7.68	21.5
1.149	19	76	17.917	+ 5.40	20
1.158	20	80	18.860	+ 3.12	18
1.167	21	84	19.803	— 0.84	15
1.176	22	88	20.746	— 4.44	12.5
1.186	23	92	21.689	— 8.03	10.5
1.196	24	96	22.632	—11.63	8
1.205	25	100	23.575	—15.23	6
1.215	26	104	24.518	—19.56	4
1.225	27	108	25.461	—24.43	1.5
1.236	28	112	26.404	—29.29	1″ vacuum
1.246	29	116	27.347	—35.30	5″ vacuum
1.257	30	120	28.290	—41.32	8.5″ vacuum
1.268	31	...	29.233	—47.66	12″ vacuum
1.279	32	...	30.176	—54.00	15″ vacuum
1.290	33	...	31.119	—44.32	10″ vacuum
1.302	34	...	32.062	—34.66	4″ vacuum
1.313	35	...	33.	—25.00	1.5 pounds

Table of Brine Solution

(Chloride of Sodium—Common Salts)

Percentage of Salt by Weight	Degrees on Salometer at 60 Degrees F.	Specific Gravity at 60 Degrees F.	Specific Heat	Weight of 1 Gallon	Pounds of Salt in 1 Gallon	Pounds of Water in 1 Gallon	Weight of 1 Cubic Foot	Pounds of Salt in 1 Cubic Foot	Pounds of Water in 1 Cubic Foot	Freezing Point Degrees F.
0	0	1.	1.	8.35	0.	8.35	62.4	0.	62.4	32.
1	4	1.007	0.992	8.4	0.084	8.316	62.8	0.628	62.172	31.8
5	20	1.037	0.96	8.65	0.432	8.218	64.7	3.237	61.465	25.4
10	40	1.073	0.892	8.95	0.895	8.055	66.95	6.695	60.253	18.6
15	60	1.115	0.855	9.3	1.395	7.905	69.57	10.435	59.134	12.2
20	80	1.150	0.829	9.6	1.92	7.68	71.76	14.352	57.408	6.86
25	100	1.191	0.783	9.94	2.485	7.455	74.26	18.565	55.695	1.00

TABLE 25.

thus, a compressor working under a suction pressure of 30 pounds (gage pressure) will have approximately 50 per.cent. greater capacity than one working under 15 pounds guage pressure.

To determine the refrigerating effect of the evaporation of one pound of liquid ammonia at a given back pressure, a deduction must be made from the latent heat of evaporation at that pressure for the work required to cool the ammonia itself from the temperature at which it enters the evaporating coils to the temperature at which evaporation takes place.

The temperature at which the ammonia enters the coils will be approximately that of the water used for condensing purposes.

Table 7 shows the number of cubic feet of gas that must be pumped per minuteat different suction and condensing pressures to produce one ton of refrigeration per twenty-four hours. The values given are theoretical ones, and it is assumed that the temperature of the ammonia entering the evaporation coils corresponds to the temperature of condension at the pressure given, and no allowance is made for unavoidable losses.

To obtain the net refrigerating effect of a compressor, it is, therefore, necessary to determine:

1. The suction(or back) pressure.

2. The temperature at which the ammonia enters the coils.

3. The percentage of allowance to cover unavoidable losses.

According to tests made by the York Mfg.Co., their machines are rated to run with a back pressure of 15.67 pounds above atmosphere(at which pressure ammonia evaporates at zero Fahr.) condensing water at 60 degrees Fahr., which gives ammonia liquid a temperature of about 65 degrees Fahr.; under these conditions

Table Showing Refrigerating Effect of One Cubic Foot of Ammonia Gas at Different Condenser and Suction (Back) Pressures in B. T. Units

Temperature of Gas in Degrees F.	Corresponding Suction Pressure Pounds per Square Inch	Temperature of the Liquid in Degrees F. 65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (gauge), Pounds per Square Inch 103	115	127	139	153	168	184	200	218
	G. Pres.									
—27	1	27.30	27.01	26.73	26.44	26.16	25.87	25.59	25.30	25.02
—20	4	33.74	33.40	33.04	32.70	32.34	31.99	31.64	31.30	30.94
—15	6	36.36	36.48	36.10	35.72	35.34	34.96	34.58	34.20	33.82
—10	9	42.28	41.84	41.41	40.97	40.54	40.10	39.67	39.23	38.80
— 5	13	48.31	47.81	47.32	46.82	46.33	45.83	45.34	44.84	44.35
0	16	54.88	54.32	53.76	53.20	52.64	52.08	51.52	50.96	50.40
5	20	61.50	60.87	60.25	59.62	59.00	58.37	57.75	57.12	56.50
10	24	68.66	67.97	67.27	66.58	65.88	65.19	64.49	63.80	63.10
15	28	75.88	75.12	74.35	73.59	72.82	72.06	71.29	70.53	69.76
20	33	85.15	84.30	83.44	82.59	81.73	80.88	80.02	79.17	78.31
25	39	95.50	94.54	93.59	92.63	91.68	90.72	89.97	88.81	87.86
30	45	106.21	105.15	104.09	103.03	101.97	100.91	99.85	98.79	97.73
35	51	115.69	114.54	123.39	112.24	111.09	109.94	108.79	107.64	106.49

TABLE 6.

Table Giving Number of Cubic Feet of Gas that Must Be Pumped per Minute at Different Condenser and Suction Pressures to Produce 1 Ton of Refrigeration in 24 Hours

Temperature of Gas in Degrees F.	Corresponding Suction Pressure Pounds per Square Inch	Temperature of the Gas in Degrees F. 65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (gauge), Pounds per Square Inch 103	115	127	139	153	168	184	200	218
	G. Pres.									
—27	1	7.22	7.3	7.37	7.46	7.54	7.62	7.70	7.79	7.88
—20	4	5.84	5.9	5.96	6.03	6.09	6.16	6.23	6.30	6.43
—15	6	5.35	5.4	5.46	5.52	5.58	5.64	5.70	5.77	5.83
—10	9	4.66	4.73	4.76	4.81	4.86	4.91	4.97	5.05	5.08
— 5	13	4.09	4.12	4.17	4.21	4.25	4.30	4.35	4.40	4.44
0	16	3.59	3.63	3.66	3.70	3.74	3.78	3.83	3.87	3.91
5	20	3.20	3.24	3.27	3.30	3.34	3.38	3.41	3.45	3.49
10	24	2.87	2.9	2.93	2.96	2.99	3.02	3.06	3.09	3.12
15	28	2.59	2.61	2.65	2.68	2.71	2.73	2.76	2.80	2.82
20	33	2.31	2.34	2.36	2.38	2.41	2.44	2.46	2.49	2.51
25	39	2.06	2.08	2.10	2.12	2.15	2.17	2.20	2.22	2.24
30	45	1.85	1.87	1.89	1.91	1.93	1.95	1.97	2.00	2.01
35	51	1.70	1.72	1.74	1.76	1.77	1.79	1.81	1.83	1.85

115

TABLE 7.

it requires the handling of about 7,500 cubic inches of gas per minute to produce the effect equal to the melting of one ton of ice per twenty-four hours.

The preceeding discussion pertains to the York machinery and is taken from one of the York Manufacturing Co's. descriptive catalogues.

COMPRESSOR PERFORMANCE

ILLUSTRATED BY INDICATOR CARDS.

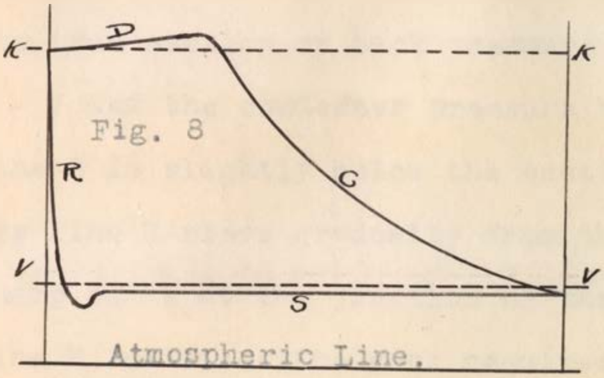


Fig. 8

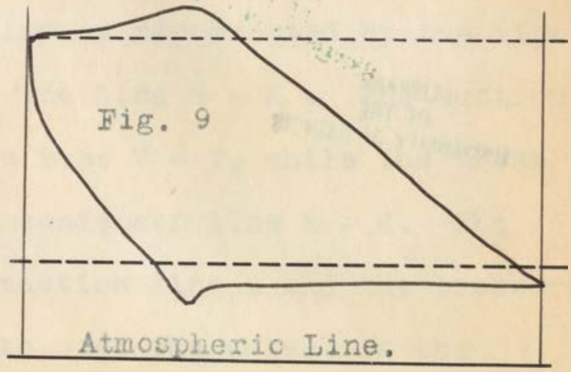


Fig. 9

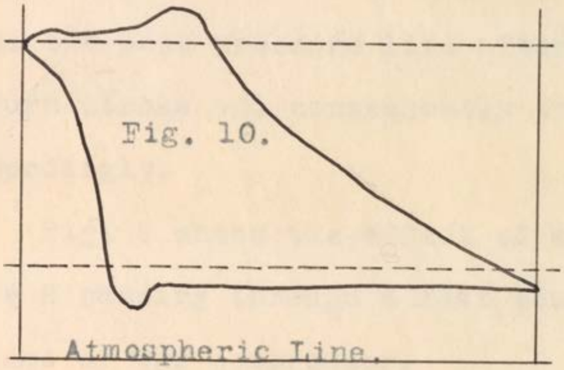


Fig. 10.

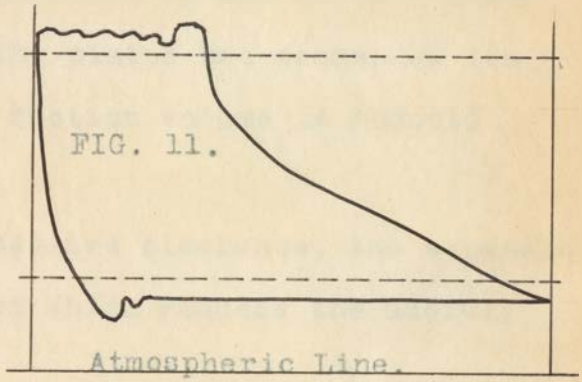


FIG. 11.

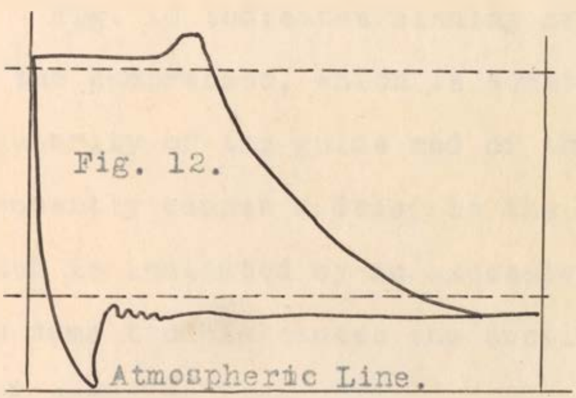


Fig. 12.

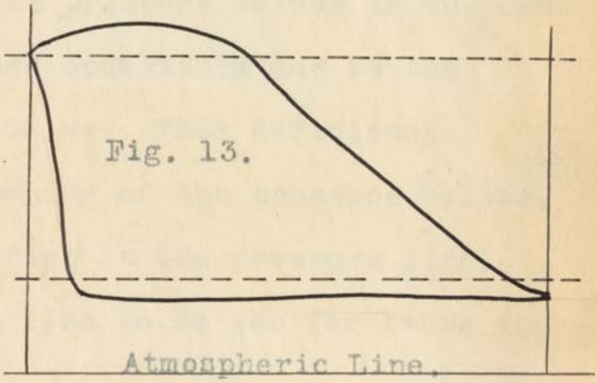


Fig. 13.

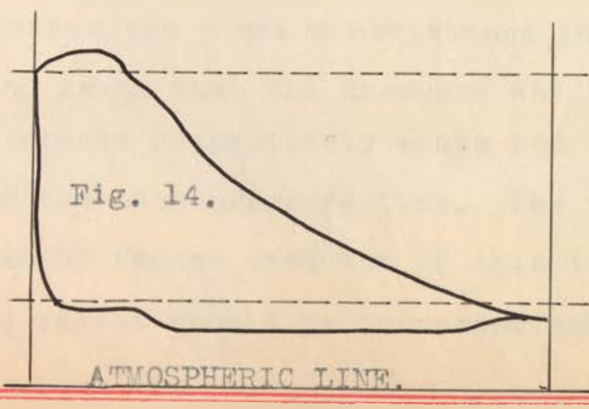


Fig. 14.

COMPRESSOR PERFORMANCE.

The compressor is working in the proper manner when it gives a card the general outline of which is shown in Fig. 8. The true suction or back pressure line is represented by the line V - V and the condenser pressure by the line K - K . The suction line S is slightly below the suction line V - V, while the pressure line D rises gradually from the condenser line K - K. The sharp curve at the junction of the suction line S and the pressure line R indicates the work required to open the valves in the piston. The effect of clearance is shown by the curve R which cuts the back pressure line after the piston has commenced its return stroke and consequently the suction volume is reduced accordingly.

Fig. 9 shows the effect of excessive clearance, the expansion line R passing through a flat course which reduces the useful volume of the compressor.

Fig. 10 indicates binding of the pressure valves in the head of the compressor, which is sometimes occasioned due to the angularity of the guide rod of the valve. This deficiency frequently causes a delay in the opening of the pressure valves, which is indicated by an excessive rise in the pressure line. The same trouble causes the suction line to be too far below the back pressure line.

Fig. 11 indicates too great a resistance in the pressure and suction piping and means that the pressure and suction lines are at too great a distance respectively above and below the condenser pressure line and the back pressure line. The valve spring should be replaced by weaker ones and if this does not help then the pipe line and valves should be inspected and cleaned.

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Fig. 12 indicates binding of the suction valve which causes a delay in compression besides absorbing considerable energy.

Fig. 13 shows that the compressor valves leak. The compression line gradually merges into the pressure line and the back expansion passes gradually into the suction line. If the main leak is in the pressure valve the compression curve will be nearly a straight line and very steep. If the main leak is in the suction valve the compression line will run a flat course.

Fig. 14 indicates that the piston is not well packed , the leakage permitting vapor to pass from one side of the piston to the other , thus causing a very gradual compression and as a result a compression line having a flat course. A longer time is taken before the suction line reaches its normal level on the return stroke, because the suction valve is prevented from opening until such time as the velocity of the piston is sufficient in amount to fill the suction space. The pressure then gradually deminishes and the suction valve begins to act.

Several of the above mentioned defects may, of course, exist at the same time.

Maximum efficiency of compressor performance is secured when there is as complete a discharge of gas from the cylinders as is practically possible and a removal during compression of the greatest amount of heat possible. It is of great importance in this connection to have almost perfect stuffing boxes, pistons, valves, and lubricators.

CAPACITY OF ICE MACHINES.

It is usual to express the capacity of an ice and refrigerating machine in tons of refrigeration. A ton of refrigeration is expressed as the number of heat units required to melt one ton of ice at 32 degrees F. into water at 32 degrees F. or 284000 B.t.u. since the latent heat of fusion of ice is 142 B.t.u. per pound. The ice capacity of a plant is of course different from the refrigerating capacity, the former depending upon the temperature of the water when placed in the can .

USES OF REFRIGERATION.

Mechanical refrigeration has given rise to two important world industries, namely cold storage and artificial ice manufacture, and besides is extensively used in various chemical and manufacturing industries. A partial list of the places where mechanical refrigerating machinery is used is as follows:

Can ice-making plants	Chemical works	Ocean Vessels
Plate ice-making plants	Sugar refineries	Apartment houses
Beer breweries	Paraffine works	Office buildings
Ale Breweries	Oil refineries	Molasses factories
Cold storage house	Lard factories	Skating rinks
Groceries	Distelleries	Steel tempering
Markets	Laundries	Photography
Packing houses	Glue works	Dry plate works
Abattoirs	Wineries	Stearine factories
Fish curing plants	Hotels	Chocolate factories
Daries	Restaurants	Paint factories
Ice-cream factories	Hospitals	Soap factories

Table 8 gives the temperatures used in cold storage for different products, and table 8 the specific and latent heat of various food products.

Cold Storage Temperatures

Articles	Degr. Fahr.
Fruit	
Apples	32–36
Bananas	34
Berries, fresh	36
Cranberries	33–36
Cantaloupes	40
Dates, figs, etc.	50–55
Fruits, dried	35–40
Grapes	34–36
Lemons	33–36
Oranges	34–36
Peaches	34–36
Pears, watermelons	34–36
Meats	
Brined	38
Beef, fresh	33
Beef, dried	36–40
Calves	32–33
Hams, ribs, shoulders (not brined)	20
Hogs	29–32
Lard	38
Livers	20–30
Sheep, lambs	32
Ox-tails	30
Sausage casings	20
Tenderloin, butts, etc.	33

Articles	Degr. Fahr.
Fish	
Fresh fish	20
Dried fish	36
Oysters in shell	30–35
Oysters in tubs	25
Canned Goods	
Sardines	35–40
Fruits	35–40
Meats	35–40
Butter, Eggs, etc.	
Butter	18–20
Butterine	18–20
Cheese	34
Eggs	31
Liquids	
Beer, ale, porter, etc.	33
Cider	30
Ginger ale	36
Wines	40–45
Flour and Meal	
Buckwheat flour	36–40
Corn meal	36–40
Oat meal	36–40
Wheat flour	36-40

Articles	Degr. Fahr.
Vegetables	
Asparagus	34–35
Cabbage	34–35
Carrots	34–35
Celery	34–35
Dried beans	32–40
Dried corn	35
Dried peas	35-40
Onions	36
Parsnips	34–35
Potatoes	36–40
Sauerkraut	35
Miscellaneous	
Cigars, tobacco	35
Furs, woolens, etc.	35
Honey	45
Hops	40
Maple syrup, sugar	40-45
Oils	35
Poultry, dressed, iced	28–30
Poultry, dry picked	26–28
Poultry, scalded	20
Game, to freeze	15–18
Game, after frozen	25–28
Poultry, to freeze	15–18
Poultry, after frozen	25–28
Nuts in shells	35–40
Chestnuts	33

TABLE 8.

Specific and Latent Heat of Various Food Products

Substance	Composition		Specific Heat Above Freezing in Heat Units	Specific Heat Below Freezing in Heat Units	Latent Heat of Freezing in Heat Units
	Water	Solids			
Lean beef	72.00	28.00	0.77	0.41	102
Fat beef	51.00	49.00	.60	.34	72
Veal	63.00	37.00	.70	.39	90
Fat Pork	39.00	61.00	.51	.30	55
Eggs	70.00	30.00	.76	.40	100
Potatoes	74.00	26.00	.80	.42	105
Cabbage	91.00	9.00	.93	.48	129
Carrots	83.00	17.00	.87	.45	118
Milk	87.50	12.50	.90	.47	124
Oysters	80.38	19.62	.84	.44	114
Whitefish	78.00	22.00	.82	.43	111
Eels	62.07	37.93	.69	.38	88
Lobster	76.62	23.38	.81	.42	108
Pigeon	72.40	27.60	.78	.41	102
Chicken	73.70	26.30	.80	.42	105

The figures in the last column showing the latent heat of freezing, have been obtained by multiplying the latent heat of freezing water, which is 142 heat units, by the per cent. of water contained in the different materials considered, for as the solid constituents remain in their original condition, only the liquid or watery portion of these materials are concerned in the solidification or freezing of them.

TABLE 9.

Table of Properties of Saturated Steam

Gauge Pressure per Square Inch, in Pounds	Pressure Above Vacuum per Square Inch in Pounds	Temperature in Degrees F.	Total Heat in Heat Units at 32 Degrees F.	Heat in Liquid from 32 Degrees in Heat Units	Heat of Vaporization or Latent Heat in Heat Units	Density or Weight of 1 Cubic Foot in Pounds	Volume of 1 Pound in Cubic Feet	Factor of Equivalent Evaporation at 212 Degrees F.
......	1	101.99	1113.1	70.0	1043.0	0.00299	334.50	0.9661
......	2	126.27	1120.5	94.4	1026.1	0.00576	173.60	.9738
......	3	141.62	1125.1	109.8	1015.3	0.00844	118.50	.9786
......	4	153.09	1128.6	121.4	1007.2	0.01107	90.33	.9822
......	5	162.34	1131.5	130.7	1000.8	0.01366	73.21	.9852
......	6	170.14	1133.8	138.6	995.2	0.01622	61.65	.9876
......	7	176.80	1135.9	145.4	990.5	0.01874	53.39	.9897
......	8	182.92	1137.7	151.5	986.2	0.02125	47.06	.9916
......	9	188.33	1139.4	156.9	982.5	0.02374	42.12	.9934
......	10	193.25	1140.9	161.9	979.0	0.02621	38.15	.9949
.0	14.7	212.00	1146.6	180.7	966.0	0.03793	26.78	1.0000
.03	15	213.03	1146.9	181.8	965.1	0.03826	26.14	1.0003
5.3	20	227.95	1151.5	196.9	954.6	0.05023	19.91	1.0051
10.3	25	240.04	1155.1	209.1	946.0	0.06199	16.13	1.0099
15.3	30	250.27	1158.3	219.4	938.9	0.07360	13.59	1.0129
20.3	35	259.19	1161.0	228.4	932.6	0.08508	11.75	1.0157
25.3	40	267.13	1163.4	236.4	927.0	0.09644	10.37	1.0182
30.3	45	274.29	1165.6	243.6	922.0	0.1077	9.285	1.0205
35.3	50	280.85	1167.6	250.2	917.4	0.1188	8.418	1.0225
40.3	55	286.89	1179.4	256.3	913.1	0.1299	7.698	1.0245
45.3	60	292.51	1171.2	261.9	909.3	0.1409	7.097	1.0263
50.3	65	297.77	1172.7	267.2	905.9	0.1519	6.583	1.0280
55.3	70	302.71	1174.3	272.2	902.1	0.1628	6.143	1.0295
60.3	75	307.38	1175.7	276.9	898.8	0.1736	5.760	1.0309
65.3	80	311.80	1177.0	281.4	895.6	0.1843	5.426	1.0323
70.3	85	316.02	1178.3	285.8	892.5	0.1951	5.126	1.0337
75.3	90	320.04	1179.6	290.0	889.6	0.2058	4.859	1.0350
80.3	95	323.89	1180.7	294.0	886.7	0.2165	4.619	1.0362
85.3	100	327.58	1181.9	297.9	884.0	0.2271	4.403	1.0374
90.3	105	331.13	1182.9	301.6	881.3	0.2378	4.205	1.0385
95.3	110	334.56	1184.0	305.2	878.8	0.2484	4.026	1.0396
100.3	115	337.86	1185.0	308.7	876.3	0.2589	3.862	1.0406
105.3	120	341.05	1186.0	312.0	874.0	0.2695	3.711	1.0416
110.3	125	344.13	1186.9	315.2	871.7	0.2800	3.571	1.0426
115.3	130	347.12	1187.8	318.4	869.4	0.2904	3.444	1.0435
125.3	140	352.85	1189.5	324.4	865.1	0.3113	3.212	1.0453
135.3	150	358.26	1191.2	330.0	861.2	0.3321	3.011	1.0470
145.3	160	363.40	1192.8	335.4	857.4	0.3530	2.833	1.0486
155.3	170	368.29	1194.3	340.5	853.8	0.3737	2.676	1.0502
165.3	180	372.07	1195.7	345.4	850.3	0.3945	2.535	1.0517
175.3	190	377.44	1197.1	350.1	847.0	0.4153	2.408	1.0531
185.3	200	381.73	1198.4	354.6	843.8	0.4359	2.294	1.0545
210.3	225	391.79	1201.4	365.1	836.3	0.4876	2.051	1.0576
235.3	250	400.99	1204.2	374.7	829.5	0.5393	1.854	1.0605
260.3	275	409.50	1206.8	383.6	823.2	0.5913	1.691	1.0632
285.3	300	417.42	1209.3	391.9	817.4	0.644	1.553	1.0657
310.3	325	424.82	1211.5	399.6	811.9	0.696	1.437	1.0680
335.3	350	431.90	1213.7	406.9	806.8	0.728	1.337	1.0703
360.3	375	438.40	1215.7	414.2	801.5	0.800	1.250	1.0724
385.3	400	445.15	1217.7	421.4	796.3	0.853	1.172	1.0745
485.3	500	466.57	1224.2	444.3	779.9	1.065	0.939	1.0812

TABLE 10.

APPROXIMATE COST OF ICE MAKING

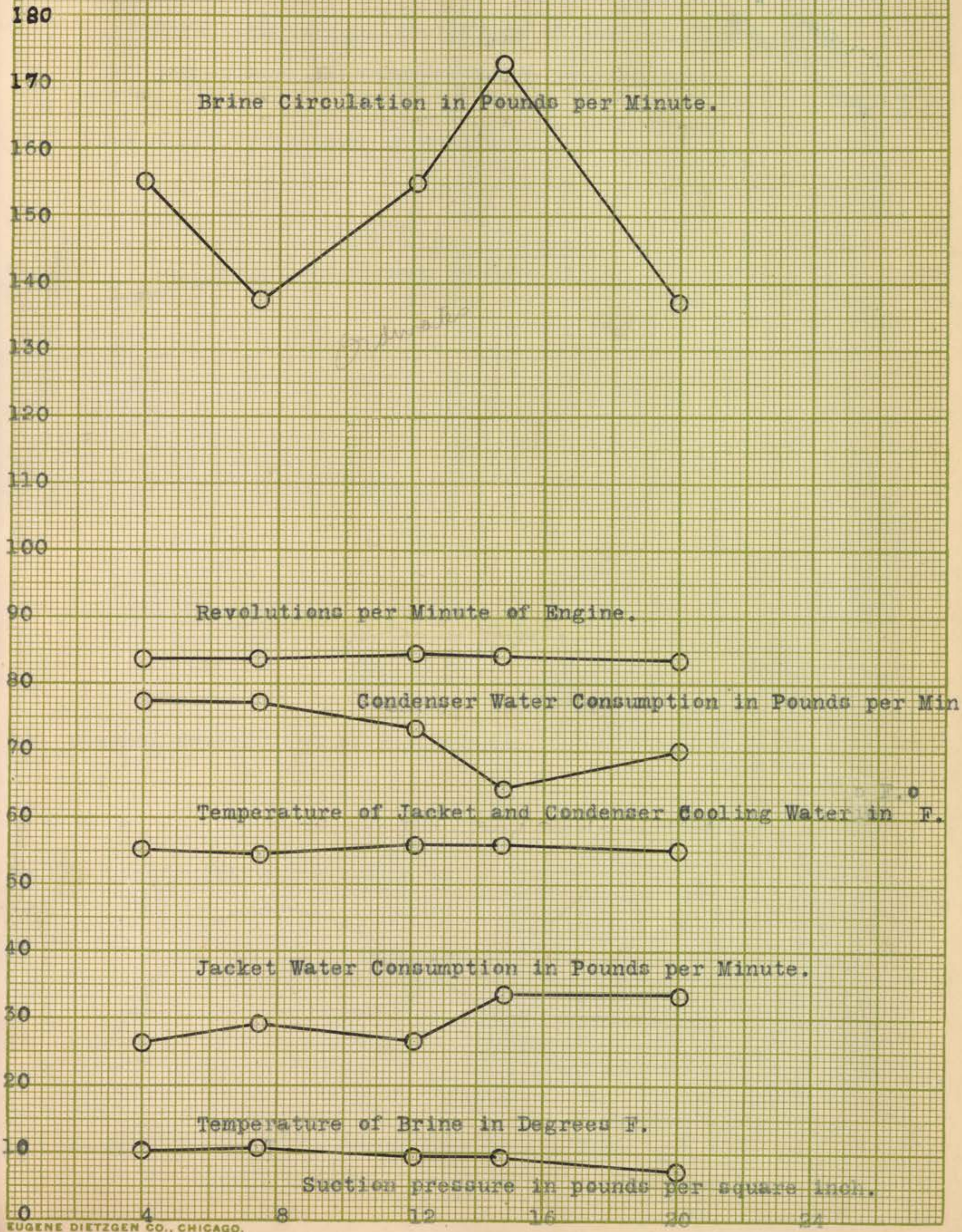
Table 11.

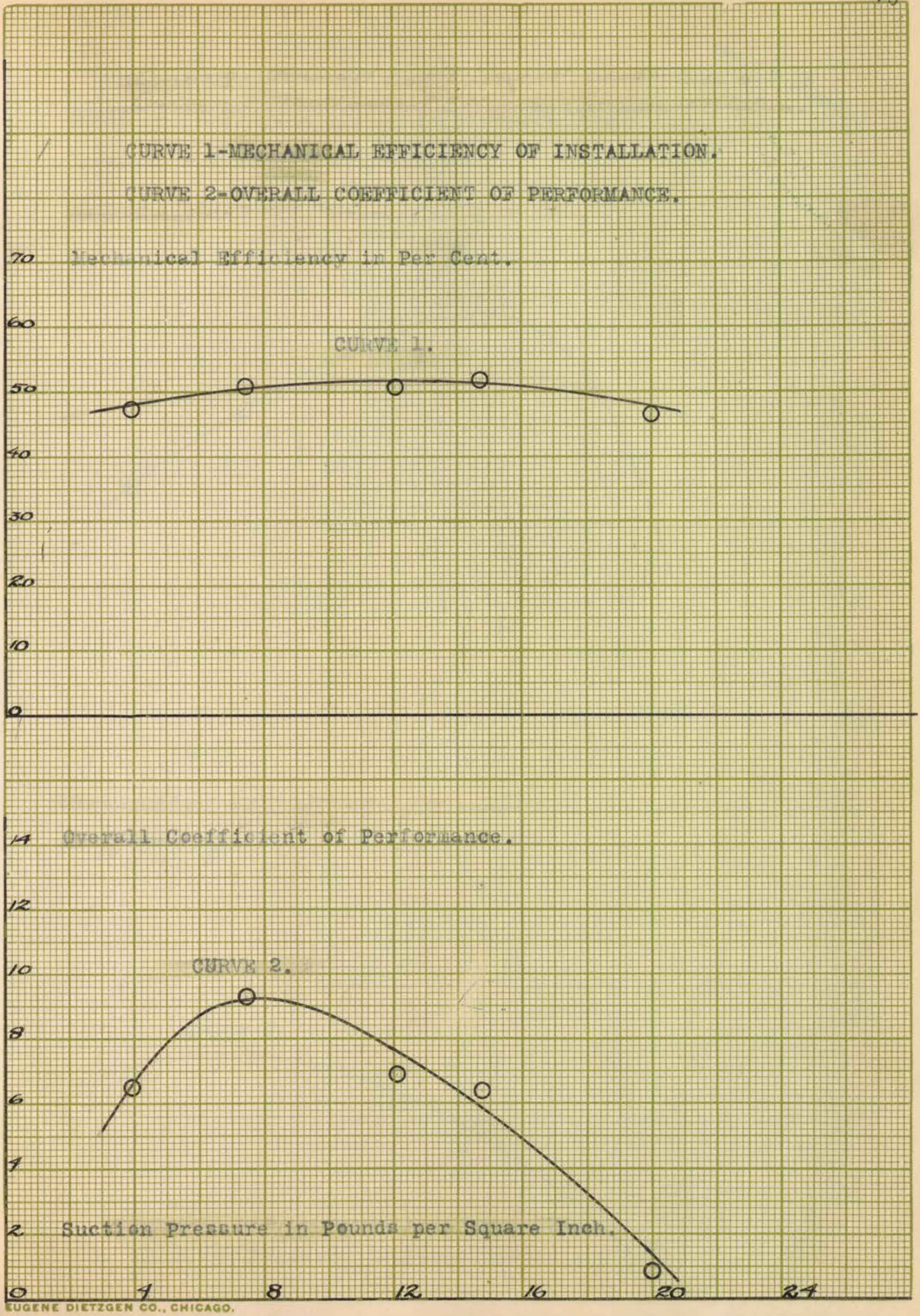
Tons of Ice per Day	Engineers \$2.50 To \$5.00 per Day	Oilers \$2.00 per Day	Firemen \$150 To \$1.75 per Day	Tankmen & Laborers \$1.25 To \$1.50	Coal \$2.00 per Ton	Oil, Waste Light and Sundries.	Daily Operating Expenses	Cost of Ice per Ton.
10	2 @ \$4.50	--------	--------	2 @ \$3.00	3600# @ \$3.60	\$1.50	\$12.60	\$1.26
20	2 @ 5.00	--------	2 @ \$3.00	2 @ 3.00	6600 @ 6.60	2.00	19.60	.98
25	2 @ 5.25	--------	2 @ 3.00	2 @ 3.00	8000 @ 8.00	2.50	21.75	.87
30	2 @ 5.50	--------	2 @ 3.00	2 @ 3.00	9300 @ 9.30	3.00	23.80	.79
40	2 @ 6.00	--------	2 @ 3.00	3 @ 4.50	12,300 @ 12.30	3.50	29.30	.76
60	3 @ 9.00	1 @ \$2.00	3 @ 4.50	3 @ 4.50	18,000 @ 18.00	4.00	42.00	.70
75	3 @ 10.00	1 @ 2.00	3 @ 4.50	4 @ 6.00	22000 @ 22.00	4.50	49.00	.65 1/3
100	3 @ 11.00	1 @ 2.00	4 @ 6.00	6 @ 9.00	28500 @ 28.50	5.00	61.50	.61 1/2
120	3 @ 11.50	1 @ 2.00	4 @ 6.00	6 @ 9.00	34000 @ 34.00	5.00	67.50	.56 1/4

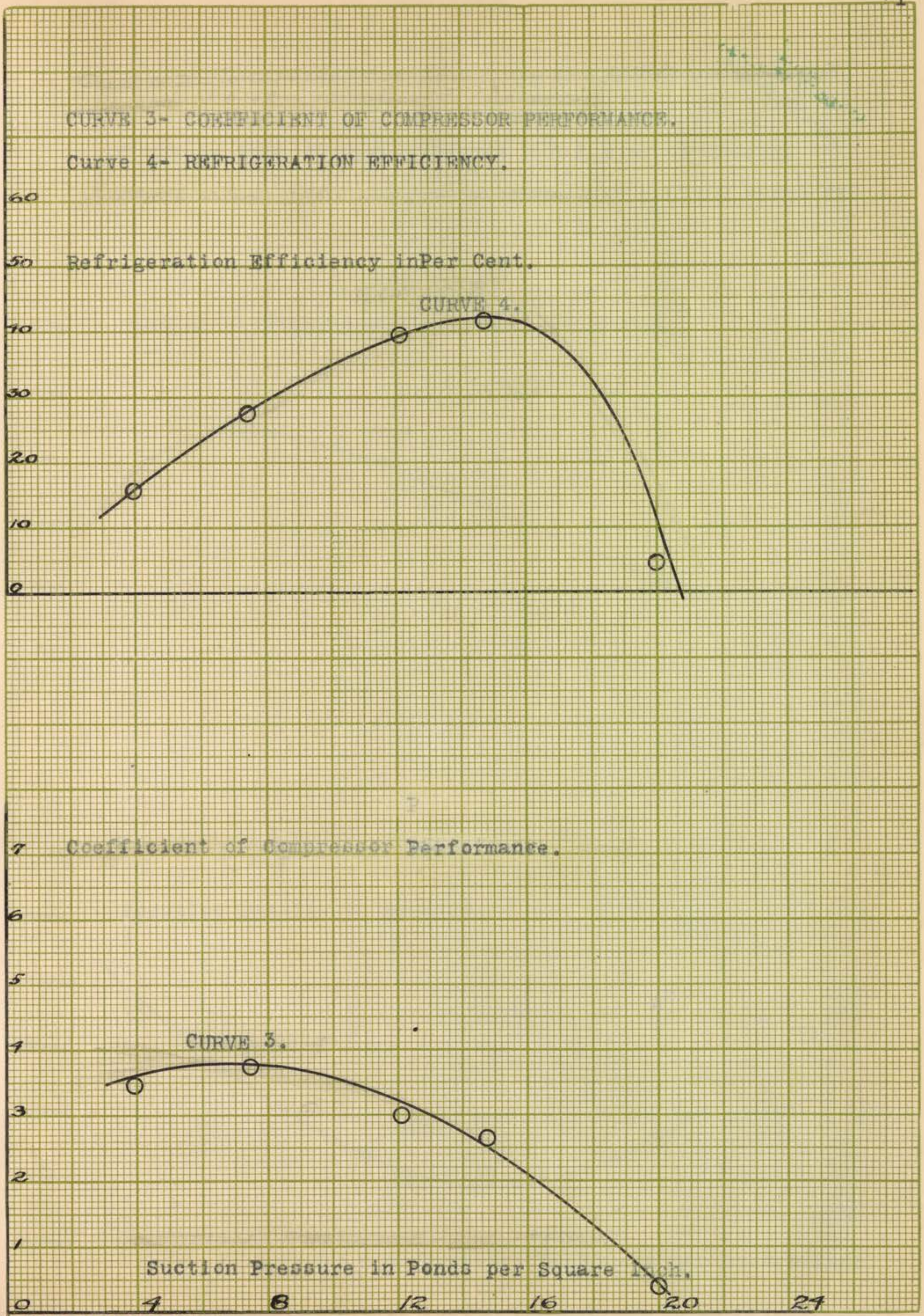
From Schmidt's
"Artificial Ice Making and Refrigeration"

OPERATION CURVES.

Ordinates as per Title of Curve.
Absissae are Suction Pressures in Pounds per sq. in

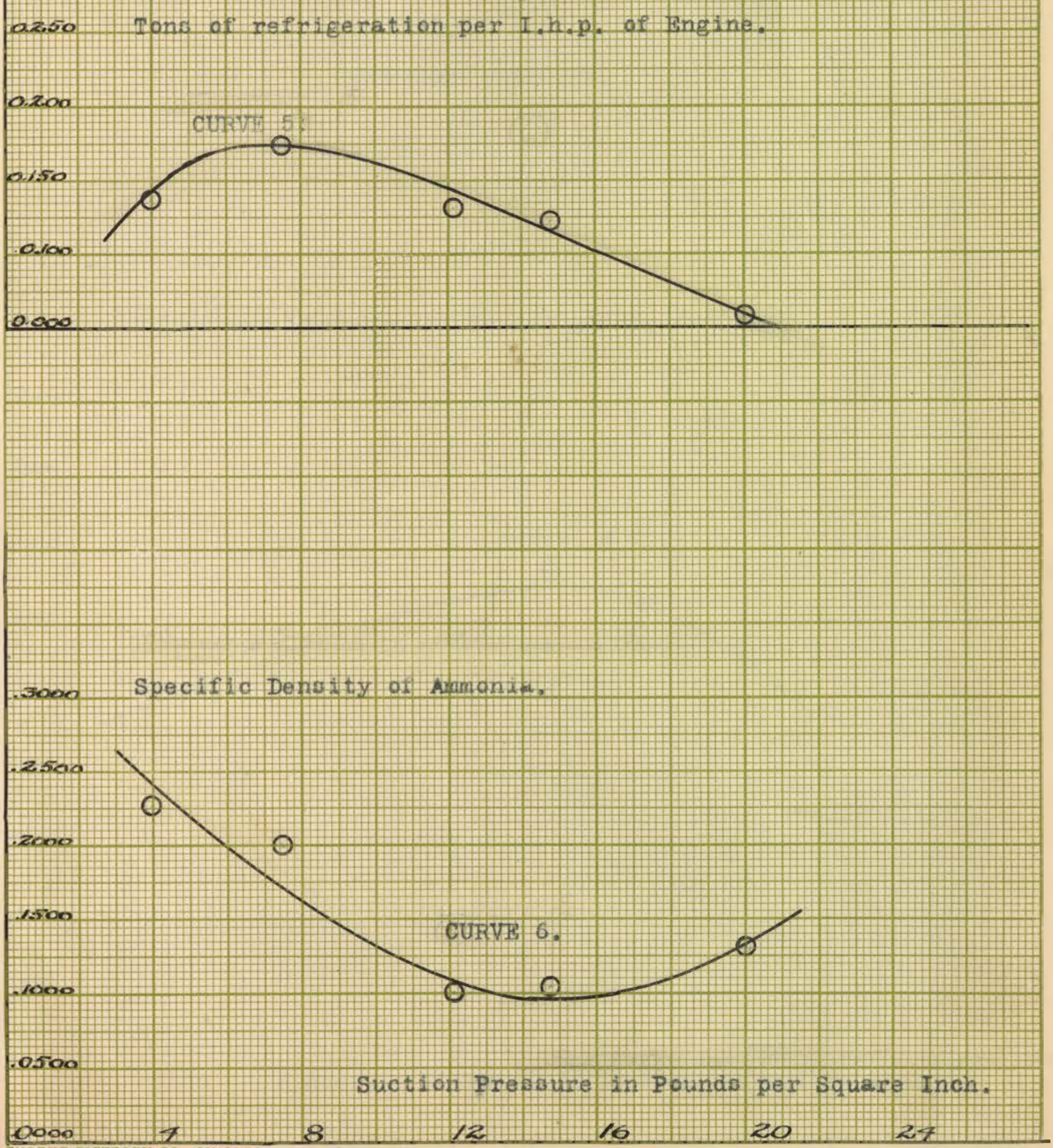



CURVE 1-MECHANICAL EFFICIENCY OF INSTALLATION.
CURVE 2-OVERALL COEFFICIENT OF PERFORMANCE.
Mechanical Efficiency in Per Cent.
70
60
CURVE 1.
50
40
30
20
10
0
Overall Coefficient of Performance.
14
12
CURVE 2.
10
8
6
4
Suction Pressure in Pounds per Square Inch.
2
0
4
8
12
16
20
24


CURVE 3- COEFFICIENT OF COMPRESSOR PERFORMANCE.
Curve 4- REFRIGERATION EFFICIENCY.
Refrigeration Efficiency inPer Cent.
CURVE 4.
60
50
40
30
20
10
0
Coefficient of Compressor Performance.
7
6
5
4
3
2
1
CURVE 3.
Suction Pressure in Ponds per Square Inch.
0
4
8
12
16
20
24

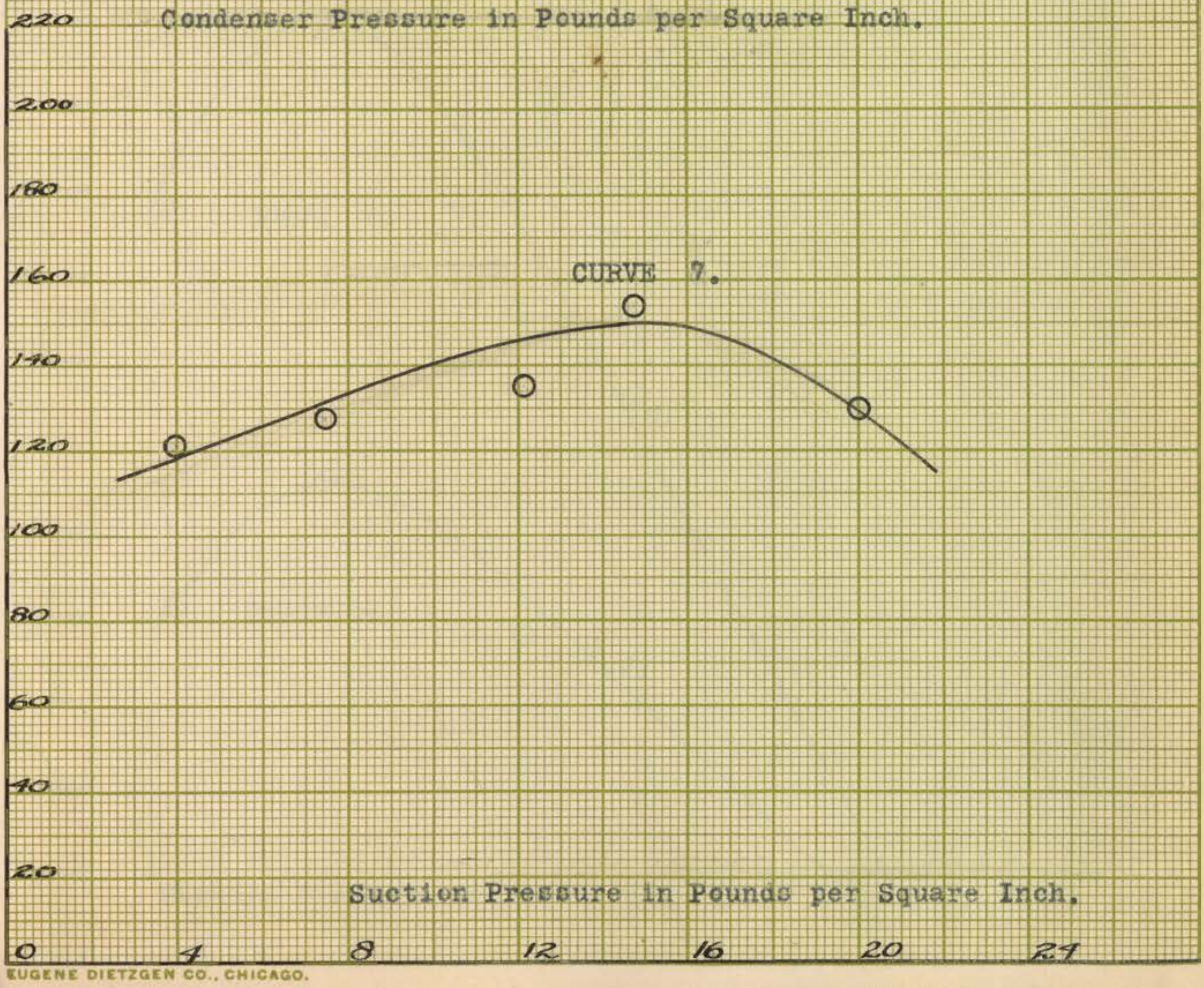
CURVE 5- TONS OF REFRIGERATION PER I.h.p. OF ENGINE.

CURVE 6- SPECIFIC DENSITY OF AMMONIA AT SUCTION PRESSURE.



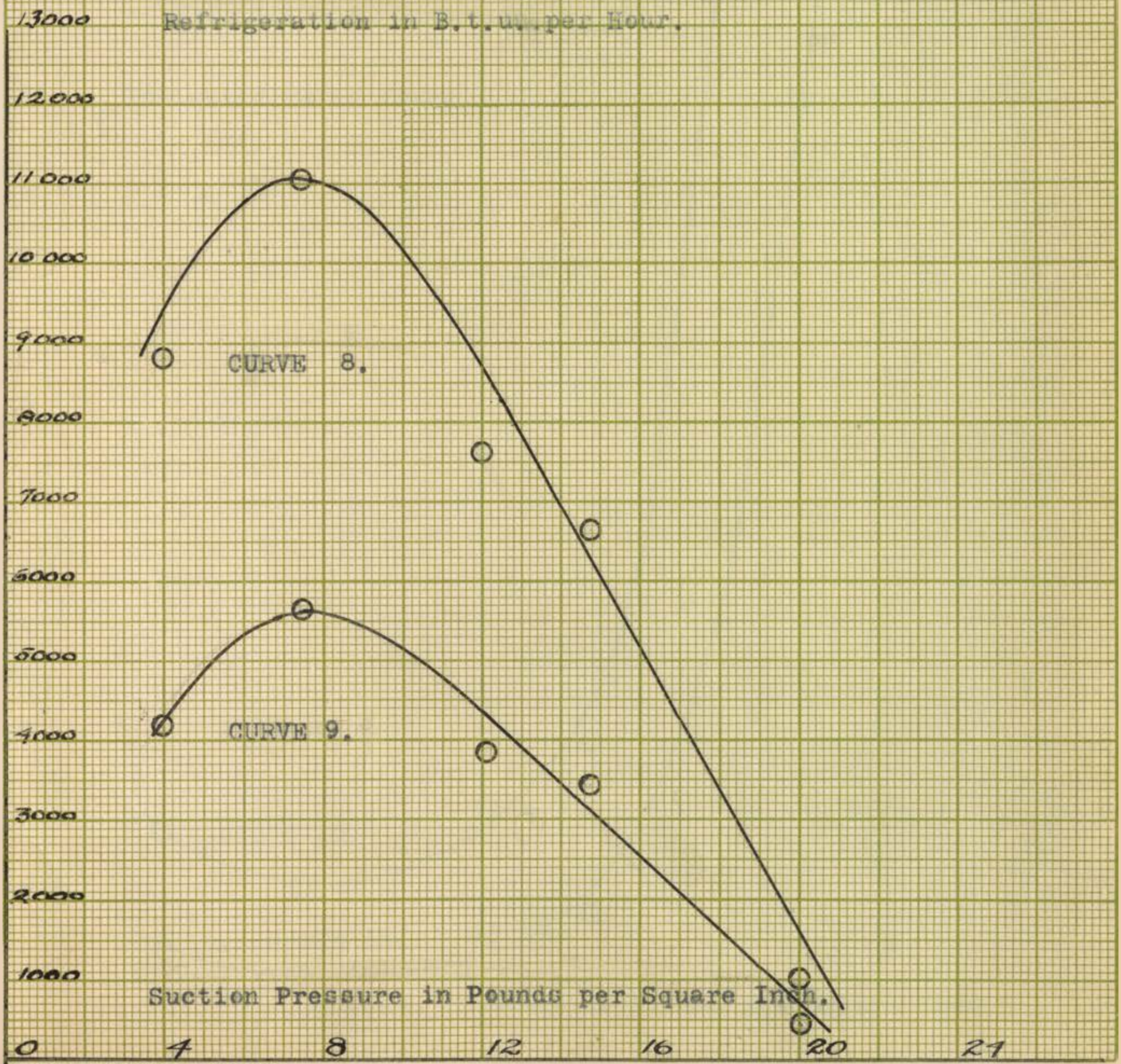
CURVE 7.

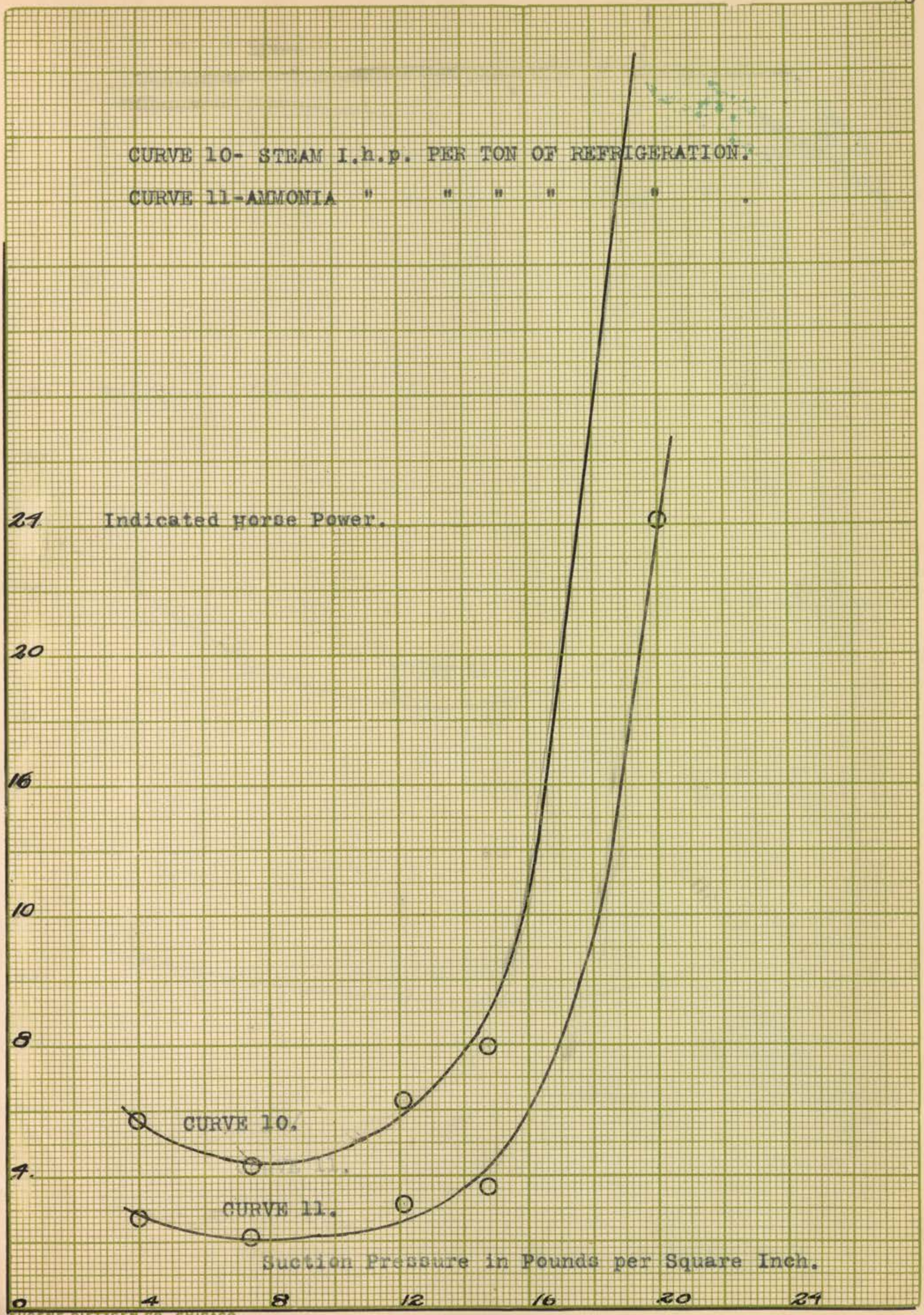
CONDENSER PRESSURE.

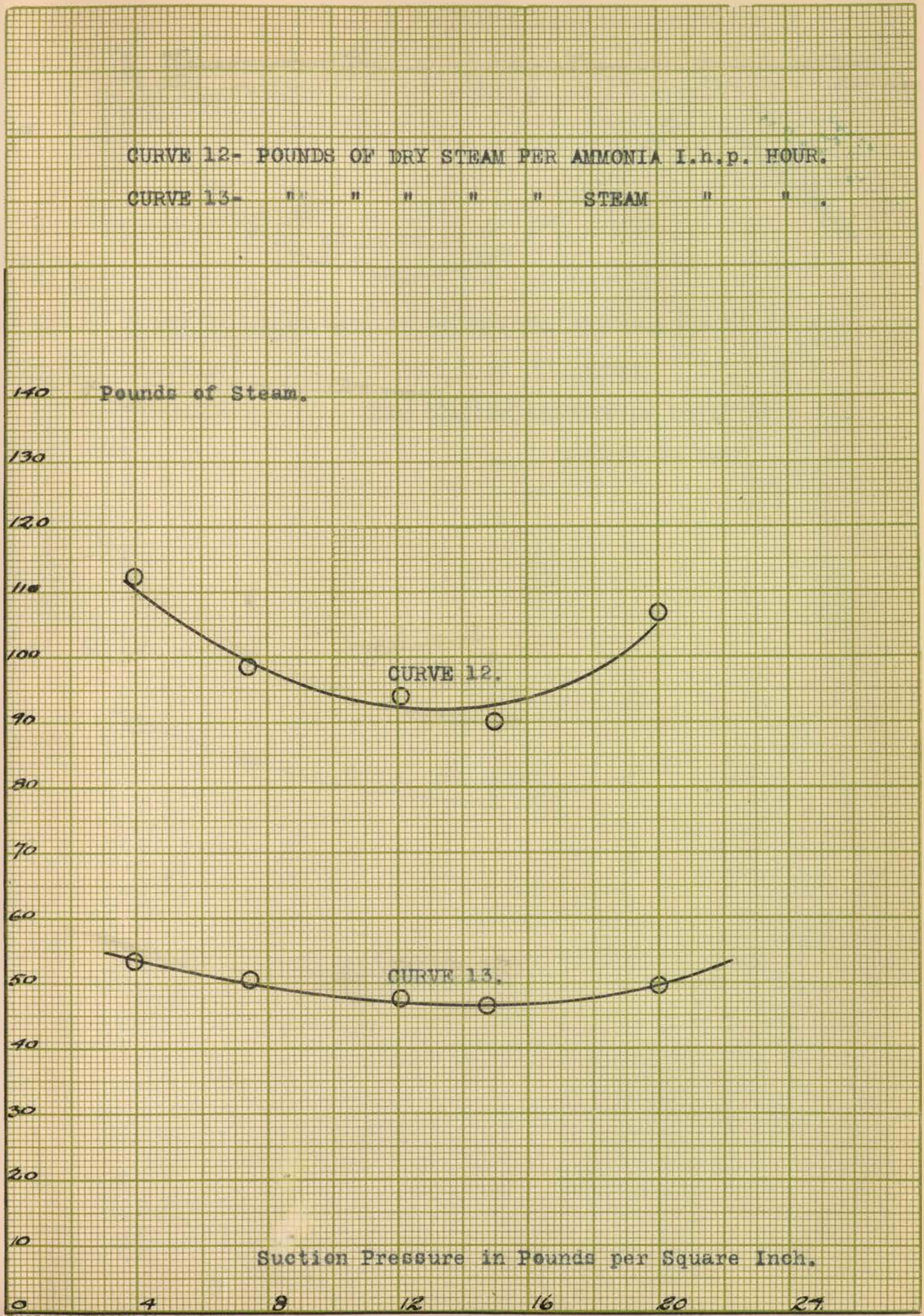


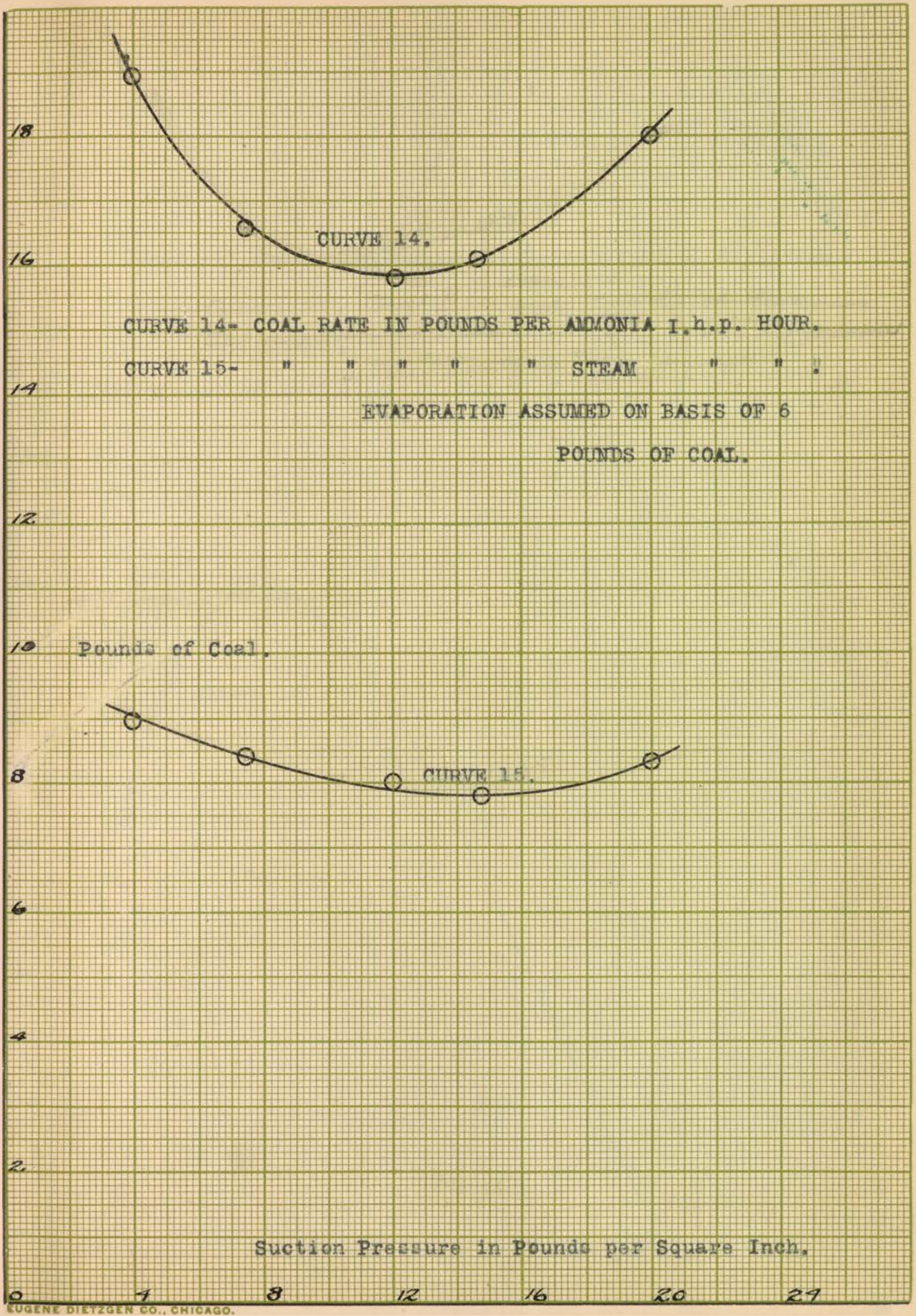
CURVE 8- REFRIGERATION IN B.t.u. PER HOUR PER STEAM I.h.p.

CURVE 9- " " " " " " AMMONIA " .

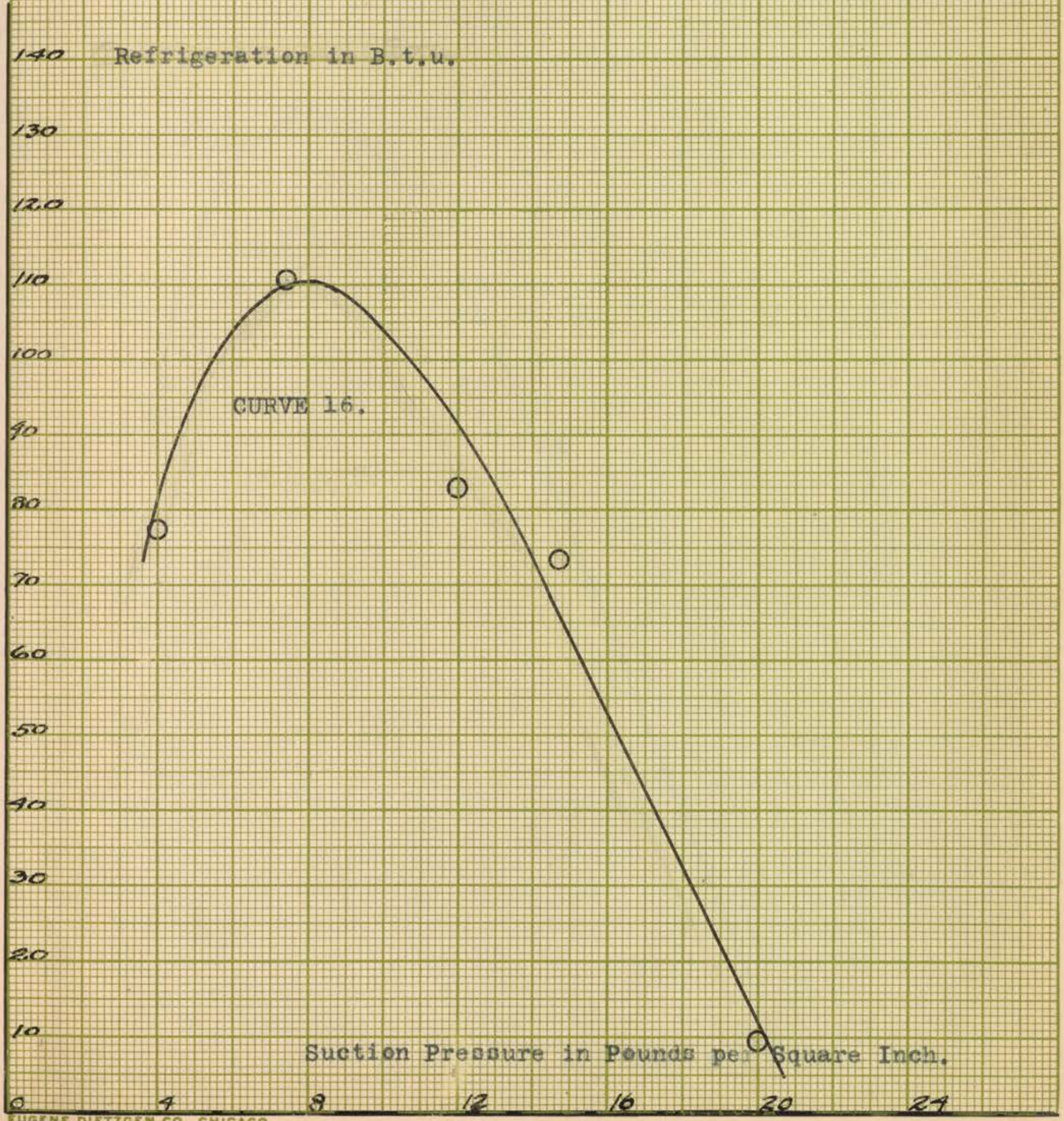


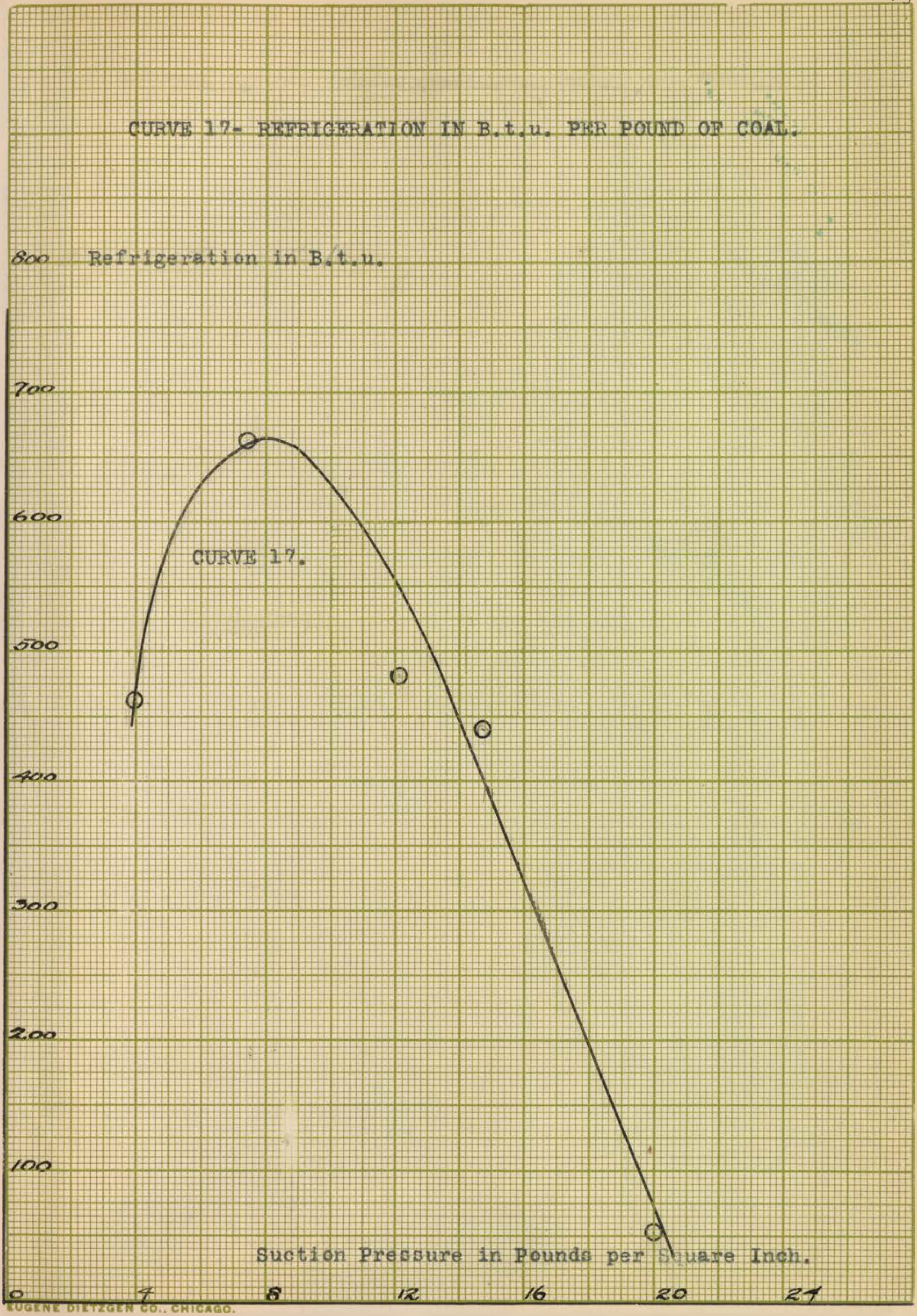

CURVE 10- STEAM I.h.p. PER TON OF REFRIGERATION.
CURVE 11-AMMONIA " " " " " .
Indicated Horse Power.
24
20
16
10
8
4
CURVE 10.
CURVE 11.
Suction Pressure in Pounds per Square Inch.
0
4
8
12
16
20
24


CURVE 12- POUNDS OF DRY STEAM PER AMMONIA I.h.p. HOUR.
CURVE 13- " " " " " STEAM " " .
Pounds of Steam.
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
CURVE 12.
CURVE 13.
Suction Pressure in Pounds per Square Inch.
4
8
12
16
20
24


CURVE 14.
CURVE 14- COAL RATE IN POUNDS PER AMMONIA I.h.p. HOUR.
CURVE 15- " " " " " STEAM " ".
EVAPORATION ASSUMED ON BASIS OF 6
POUNDS OF COAL.
Pounds of Coal.
CURVE 15.
Suction Pressure in Pounds per Square Inch.
18
16
14
12
10
8
6
4
2
0
4
8
12
16
20
24
EUGENE DIETZGEN CO., CHICAGO.

CURVE 16- Refrigeration in B.t.u. perpound of dry steam.




CURVE 17- REFRIGERATION IN B.t.u. PER POUND OF COAL.
800
Refrigeration in B.t.u.
700
600
CURVE 17.
500
400
300
200
100
Suction Pressure in Pounds per Square Inch.
0
4
8
12
16
20
24
EUGENE DIETZGEN CO., CHICAGO.

UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING DEPARTMENT

YORK REFRIGERATING MACHINE — TEST NO. 1 — F.G. ROMIG F.J. MACKEY G.Q. LEWIS — THESIS 1910

No.	Time	Temperatures: Suction	Discharge																	Heating Coils: Enter	Leave	Difference	Engine Room	Pressures: Compressor: Suction	Condenser	Engine: Steam	Exhaust at Condenser	Quantities: Strokes ... in 20 min	Counter Strokes of Engine	Rev. in 20 min Engine	Indicator Card Areas: Compressor: Left	Right	Engine: H.E.	C.E.
1	8:15	10	160	162	62	-14	7.5	8.0	12.0	4.5	54	62	8	54	70	83	76.5	22.5	106.0	85	21	65	4.5	100	130	-1	000	145	—	.45	.99	1.30	1.86
2	8:35	12	162	163.5	63	-8	7.5	8.0	12.0	4.5	54	72	18	54	72	83	77.5	23.5	130.0	105	25	67	6.5	123	125	-1	622	1985	1840	.67	.85	1.63	1.95
3	8:55	12	171	163	74	-3	7.5	8.0	12.5	5.0	54	68	14	54	70	83	76.5	22.5	150.0	111	39	67	10.0	120	133	-1	1088	3560	1575	.63	1.06	1.14	2.08
4	9:15	12	159	159	60	-7.5	8.9	9.0	14.0	5.1	54	69	15	54	71	83	77.0	23.0	146.0	95	51	68	2.0	122	134	-1	1110	5200	1640	.53	.91	1.63	1.93
5	9:35	16	164	163	70	-10.5	10.0		15.0	5.0	54	73	19	54	73	83	78.0	24.0	123.5	74	49.5	70	5.0	121	126	-1	1143	6900	1700	.66	1.10	1.80	1.94
6	9:55	19	170	170	72	-8.0	8.5	9.0	13.0	4.5	55	72	17	55	75	83	79.0	24.0	110.0	61	49	71	7.0	126	115	-1	1060	8550	1650	.69	1.15	1.70	1.96
7	10:15	21	167	168	72	-10.0	7.0	8.0	10.0	3.0	55	73	18	55	70	83	76.5	21.5	112.0	72	40	72	7.0	126	143	-1	1089	10150	1600	.70	1.00	1.68	2.00
8	10:35	28	174	174	69	-10.0	6.8	7.3	13.0	6.2	55	74	19	55	73	83	78.0	23.0	114.0	78	36	72	6.5	124	135	-1	1072	11875	1725	.73	1.03	1.90	
9	10:55	30	176	175	73	-8.5	6.9	7.2	14.5	7.6	55	73	18	55	74	76	75.0	20.0	105.5	80.5	25	73	7.5	127	138	-1	1014	13575	1700	.76	1.19	2.52	1.93
10	11:15	28	176	178	64	-8.0	7.0	7.5	14.5	7.5	54	73	19	55	71	72	72.5	17.5	112.5	85.6	26.9	73	8.0	121	139	-1.1	1073	15300	1725	.84	1.15	1.64	1.73
11	11:35	22	175	180	62	-9.3	7.0	7.6	15.0	8.0	55	73	18	55	74	82	78.0	23.0	117.8	86.	31.8	74	7.5	126.6	137	-1.2	906	17000	1700	.75	1.18	1.60	1.73
12	11:55	31	173	176	58	-14.0	7.5	8.0	15.5	8.0	55	71	16	54	74	83	78.5	24.5	118.3	89	29.3	74	4.0	121	138	-1.2	847	18775	1775	.69	1.00	1.83	1.75
13	12:15	32	178	180	72	-6.0	8.0	8.5	15.8	7.8	55	72	17	55	74	83	78.5	23.5	121.8	104	17.8	74.5	7.5	126	128	-1.2	1044	20275	1500	—	1.23	1.94	1.90
14	12:35	30	179	183	73	-4.0	8.6	8.5	16.0	7.4	55	74	19	55	74	83	78.5	23.5	120.7	100.4	20.3	75	9.5	131	128	-1.2	1102	21950	1675	.84	1.11	1.90	1.94
15	12:55	23	180	183	70	-6.0	8.5	9.0	16.1	7.6	55	74	19	55	75	83	79.0	24.0	122.8	105	17.8	75	8.0	131	133	-1.2	1100	23600	1650	.83	1.05	1.68	1.74
16	1:15	32	177	180	61	-13.5	9.0	11.0	14.0	5.0	55	71	16	55	74	83	78.5	23.5	128.0	95	33.0	75	5.0	123	136	-1.2	1150	25375	1775	.89	0.99	1.59	1.55
17	1:35	36	176	178	65	-15.0	10.0	11.0	15.0	5.0	55	70	15	55	74	81	77.5	22.5	126.5	86	40.5	76	4.0	121	140	-1.2	972	27000	1625	.85	0.86	1.90	1.87
18	1:55	34	180	183	75	-4.0	10.0	11.0	13.0	3.0	55	75	20	55	75	82	78.5	23.5	114.5	81.5	33.0	78	9.0	133	131	-1.2	1096	28500	1500	.99	1.23	1.75	1.80
19	2:15	22	181	182	76	-3.0	8.5	11.0	13.0	4.5	55	77	22	54	76	80	78.0	24.0	116.0	81.0	35.0	78		136.5	135	-1.2	1096	30375	1875	.86	1.14	1.70	1.83
20	2:35	22	180	185	73	-7.0	7.5	10.0	12.0	4.5	55	74	19	55	75	81	78.0	23.0	121.0	93.5	27.5	78	10.0	136	134	-1.2	1157	32050	1675	.86	1.20	1.60	1.66
21	2:55	32	179	182	59	-14.0	7.5	10.0	13.0	5.5	55	72	17	55	74	82	78.0	23.0	124.0	93	31.0	78	9.0	126	137	-1.2	923	33700	1650	1.05	1.00	1.80	1.86
22	3:15	34	179	182	73	-4.0	8.0	10.0	14.0	6.0	55	74	19	55	75	83	79.0	24.0	127.0	91	36.0	76	5.0	127	137	-1.2	1093	35400	1700	.94	1.17	1.83	1.80
23	3:35	20	181	185	76	-4.0	8.0	10.0	14.5	6.5	55	77	22	55	75	82	78.5	23.5	130.0	90	40.0	76	8.0	136.5	128	-1.2	1120	37150	1750	1.00	1.25	1.73	2.00
24	3:55	22	180	184	70	-7.0	8.0	10.0	13.0	5.0	55	75	20	55	75	82	78.5	23.5	133.0	92	41.0	76	11.0	136	129	-1.2	1134	38800	1650	1.00	1.18	1.78	1.87
25	4:15	32	178	183	74	-6.0	8.2	10.5	13.0	4.8	56	75	19	55	75	83	79.0	24.0	126.0	65	61.0	76	8.5	131	124	-1.2	1093	40450	1650	1.00	1.20	2.00	1.86
26	4:35	34	180	184	74	-6.0	8.0	10.0	13.0	5.0	55	75	20	56	74	88	81.0	25.0	123.0	85	38.0	76	8.0	133	128	-1.2	1140	42100	1650	.99	1.20	1.98	2.00
27	4:55	34	180	185	75	-6.0	8.0	10.5	13.0	5.0	55	76	21	55	74	88	81.0	26.0	123.5	85	38.5	75	8.0	136	128	-1.2	1090	43800	1700	1.02	1.20	1.89	1.90
28	5:15	34	181	186	75	-5.0	8.0	10.0	14.0	6.0	55	76	21	55	74	88	81.0	26.0	124.5	94	30.5	75	8.5	135	130	-1.2	1165	45500	1700	1.04	1.27	1.87	1.74
29	5:35	34	181	186	74	-5.0	8.0	10.0	13.0	6.0	55	75.5	20.5	55	75	87	81.0	26.0	128.0	96	32.0	74	8.5	134	115	-1.2	1067	47175	1675	1.03	1.29	2.00	1.86
30	5:55	32	181	185	71	-6.0	8.0	9.5	15.0	7.0	55	75	20	54	74	84	79.0	25.0	135.0	103	32.0	72	8.5	132	133	-1.1	1108	48775	1600	1.00	1.33	1.76	1.84
31	6:15	33	180	184	72	-6.0	8.6	10.0	17.0	8.5	55	73	18	54	72	84	78.0	24.0	137.0	111	26.0	70	8.5	128	141	-1.1	1145	50700	1925	.83	1.33	1.80	1.98
32	6:35	34	179	184	72	-6.0	9.5	10.5	14.0	4.5	55	73	18	55	72	85	78.5	23.5	142.0	108	34.0	69	8.0	128	133	-1.1	1005	52370	1670	1.00	1.33	1.70	1.83
33	6:55	33	179	184	73	-6.0	9.5	11.0	14.0	4.5	55	73.5	18.5	55	75	84	79.5	24.5	133.0	85	48.0	68	8.0	129	136	-1.1	1170	53850	1480	.93	1.35	1.83	1.94
34	7:15	34	178	184	73.5	-8.0	9.5	11.0	13.0	3.5	54	74	20	55	75	84	79.5	24.5	127.0	90.5	36.5	67	8.0	128	134	-1.1	1078	55600	1750	.96	1.26	1.72	1.89
35	7:35	34	178	183.5	72.5	-8.0	8.3	9.3	12.0	3.7	54	73.5	19.5	54	74	85	79.5	25.5	131.0	87	44.0	65	8.0	128	131	-1.1	1078	57200	1600	1.00	1.38	1.80	1.80
36	7:55	33	178	183.5	72.5	-8.0	7.5	9.0	10.0	2.5	55	74	19	55	75	84	79.5	24.5	122.0	86	36.0	65	8.0	130	126	-1.1	1178	58925	1725	.92	1.32	1.80	1.90
37	8:15	33	177	183.5	73	-8.0	6.8	8.0	11.0	4.2	56	74	18	55	75	85	80.0	25.0	115.0	79	36.0	65	7.5	131	125	-1.1	1134	60591	1666	—	1.34	1.80	2.25

University of Illinois
Mechanical Engineering Department

[illegible] Refrigerating Machine — Test No 2 — F.G. Romig F. J. Machey G.Q. Lewis — [illegible] 1910

No.	Time	Suction																															
1	6:00	29	169	173.5	64	-20	7	9	10	3	56	70	14	55	68	85	76.5	21.5	138	91	47	59	3.5	123	135	-1.0	000	000		.83	1.15	1.09	1.14
2	6:20	31	172	177.5	71	-15	8	8	12	4	57	70.5	13.5	56	68.5	85.5	77	26	141	94	47	58	4.5	123	136	-1.0	1291	1675	1675	.86	1.28	1.28	1.23
3	6:40	32	172	178.	70	-18	9	9	13	4	57	69	12	56	68.5	85	76.7	20.7	144	95	49	57	4.5	121	126	-1.0		3275	1600	.65	1.22	1.12	1.28
4	7:00	30	175	180.5	71	-14	9.5	11.5	13	3.5	57	70	13	55	68.5	86	77.2	22.2	141	93	48	63.5	5.0	122	115	-1.0		5100	1825	.85	1.33	1.25	1.28
5	7:20	30	173	178	67	-18	10	10	13	3	56	68	12	55	68	83	75.5	20.5	118.5	80	38.5	59	4.0	120	123	-1.0	1178	6700	1600	.84	1.12	1.09	1.34
6	7:40	33	172.5	176	69.5	-18	9.5	10	11	1.5	56	68	12	55	70	82	76.	21.0	121	90	31	57	4.0	120	135	-1.0	1325	8975	2275	.57	1.13	1.00	1.37
7	8:00	30	173.5	176.5	70.5	-17	9	9.5	11	2	56	69	13	55	70.5	84	77.3	22.3	127	88.5	38.5	57	4.0	121	128	-1.0	1030	10100	1125	.82	1.19	1.07	1.36
8	8:20	33	172.5	175	69.5	-18	9	10	13	4	57	68.5	11.5	55	69.5	83.5	76.8	21.8	138	93	45	56	3.5	118	130	-1.0	1220	11826	1725	.78	1.23	1.00	1.35
9	8:40	33	172.5	175.5	70	-16	10.3	11	14	3.7	56	69	13	56	69	83	76.	20.0	135	88.5	46.5	56	4.5	120.5	135	-1.0	940	13500	1675	.78	1.13	1.13	1.35
10	9:00	33	171.0	174	69	-18	10	10.5	12	2	56	68	12	55	69.5	83	76.5	21.5	135	93	42	57	3.0	116	135	-1.0	1250	15400	1900	.72	1.19	1.08	1.31
11	9:20	33	172.	175	70	-15	10	10.5	12	2	56	69	13	55	70	83.5	76.8	21.8	128	92	36	56.5	4.5	120.5	134	-1.0	1131	16900	1500	.65	1.11	1.18	1.34
12	9:40	32	171.5	175.5	69.5	-18	9.5	10.3	11	1.5	56	69	13	55	69	83	76	21.0	131	96	35	56.5	4.5	120	134	-1.0	1104	18600	1700	.61	1.12	1.05	1.37
13	10:00	35	163	167	66	-20	9	9.5	11	2	56	66.5	10.5	55	68.5	81	74.7	19.7	123	90	33	56	3.0	116	136	-1.0	1120	20050	1450	.64	1.04	1.00	1.32
14	10:20	35	161.5	165	68	-18	8.5	10	10.5	2	56	66	10	55	68.5	84	76.3	21.3	121	82	29	56.5	4.0	116	139	-1.0	1175	21550	1500	.69	1.15	0.85	1.53
15	10:40	32	170.	173	70	-18	8	9.2	10	2	56	69	13	55	69	82.5	75.8	20.8	131	91	40	64	4.0	120	128	-1.0	1168	23175	1625	.60	1.10	1.20	1.21
16	11:00	32	173	181	70	-17	7.5	9	10	2.5	56	69	13	55	69	84	76.5	21.5	130.5	94	36.5	64.5	3.5	120.5	138	-1.1	1172	24875	1700	.67	1.12	1.23	1.21
17	11:20	31	176	179	71	-16	7.5	9	11	3.5	57	70	13	55	70.5	85	77.8	22.8	145	91	54	65	4.5	122	136	-1.1	1170	26600	1725	.68	1.19	1.26	1.23
18	11:40	32	176	179.5	71.5	-15	8	9	11.5	3.5	56	69.5	13.5	55	70	84.5	77.3	22.3	135	87	48	61.5	4.5	123	138	-1.1	1169	28275	1675	.82	1.18	1.13	1.27
19	12:00	34	174.5	178.5	70.5	-16	9	9	12	3	56	69	13	55	70	84	77.0	22.0	132	85	47	63	4.0	121	139	-1.1	1301	29900	1625	.83	1.04	1.18	1.21
20	12:20	34	175.5	179.5	71	-16	9	11	12.7	3.7	56	69	13	53	69	84	76.5	21.5	142.5	86	56.5	69	4.0	121	129	-1.1	1100	31725	1825	.80	1.18	1.18	1.21
21	12:40	35	177	181	70	-18	8.9	10	10.3	1.4	56	70	14	55	70	85	77.5	22.5	130	96	34	68.5	4.5	123	130	-1.0	1190	33400	1675	.82	1.21	1.10	1.22
22	1:00	36	176	180	69	-17	8.5	9.7	11	2.5	56	67	11	55	68	84	76.0	21.0	138	91	47	71	4.0	120	136	-1.0	1250	—	1675	.84	1.13	1.10	1.20
23	1:20	35	176	179	70.5	-16	8	9.5	13.5	5.5	56	69	13	55	71	86.5	75.8	20.8	138	95	43	72	4.0	120	144	-1.0	—	36750	1675	.87	1.16	1.03	1.18
24	1:40	34	177.5	180.5	71.	-16	8	9	10	2	56	71	15	55	67.5	87.5	77.5	22.5	142	97	45	71	4.5	123	135	-1.0	—	38575	1825	.82	1.19	1.12	1.30
25	2:00	33	177.5	181	71	-17	8	9.2	—	—	57	69.5	12.5	55	68	85.5	76.8	21.8	—	—	—	72	4.0	122	142	-1.0	1100	40225	1650	.73	1.17	1.10	1.28
26	2:20	34	177	181	71	-17	7.8	8.5	10	22	57	69.5	12.5	56	68	85	76.5	20.5	125	87	38	72	4.0	122.5	136	-1.0	1100	41826	1600	.78	1.14	1.13	1.24
27	2:40	34	177	181	71.5	-17	7	7.9	9	2	57	69	12	56	69	85	77.0	22.0	125	87	38	73	4.0	122.5	129	-1.0	1215	43500	1675	.79	1.14	1.10	1.20
28	3:00	34	177	181	71	-17	7	9.2	11	4	56	69	13	55	69.5	85.5	77.0	22.0	133	83	50	73	4.0	122.5	136	-1.0	1228	45150	1650	.80	1.11	1.10	1.22
29	3:20	35	177	181.5	71.5	-17	8	9	12	4	56	69	13	55	70.5	86	78.2	23.2	136	93.5	42.5		3.5	123	135	1.0	1172	46850	1700	.70	1.08	1.14	1.20
30	3:40	37	176	181	71	-17	8.5	10	13	4.5	56	69	13	55	70	86	7.8.0	23.0	140	95	45		3.75	122	144	-1.0	1225	48550	1700	.80	1.07	1.10	1.25
31	4:00	38	175	180.5	71.5	-17	9.5	11.8	14	4.5	56	69.5	13.5	55	70	86	78.0	23.0	140	97	43	65	3.5	123	133	-1.0	1150	50225	1675	.84	1.15	1.10	1.20
32	4:20	38	175	180.5	70.5	-17	10	9.5	13	3	51	69	18	55	70	86	78.0	23.0	138	91	47	63.5	3.5	122	135	-1.0	1225	51900	1675	.81	1.18	1.08	1.24
33	4:40	38	175	180.5	70.5	-17	9.9	10.5	11.5	1.6	56	69	13	55	70	85	77.5	22.5	135.5	85	50.5	69	3.5	122	135	-1.0	1225	53575	1675	.70	1.13	1.14	1.20
34	5:00	37	175.5	181	71	-18	9.8	8.5	11	1.2	56	69	13	55	71	86	78.5	23.5	139	89	50	69	4.0	123	145	-1.0	1175	55275	1700	.82	1.16	1.10	1.18
35	5:20	37	174.5	180	70	-18	9	8	10	1.	56	69	13	55	71.5	86	73.8	18.8	130	79	51	67	3.75	121	126	-1.0	1173	56925	1650	.73	1.12	1.10	1.18
36	5:40	37	174	179.5	70	-18	7.5	7.8	9	1.5	56	68	12	55	71.5	85.5	78.5	23.5	133	86	47	60	4.0	121	140	-1.0	1252	58675	1750	.77	1.10	1.06	1.22
37	6:00	37	173	179	70	-15	7	—	9	2	56	68	12	55	70	85	77.5	22.5	131	85	46	65	3.75	121	142	-1.0	1130	60305	1630	.70	—	1.14	1.10

University of Illinois
Mechanical Engineering Department

York Refrigerating Machine

Test No. 3

F. G. Romig F. J. Mackey G. Q. Lewis

No.	Time	Suction												Enter					Enter	Leave	Difference												
1		6.0	68	68	67	18	8.0	10.5	9.7	1.7	56	67	11	54.5	57	58.5	57.8	3.3				66	20	136	140	-1.2	00	00		.98	1.75	1.73	1.73
2		7.0	73	73	72	18	8.0	9.0	8.8	0.8	56	71	15	55	58	60	59.0	4.0				68	20	126	130	-1.2	469	826	826	1.03	1.89	1.74	1.67
3		7.0	74.5	74	73.5	18	7.7	8.0	8.0	0.3	56	72	16	55	59	61	60.0	5.0				68	20	119.5	123	-1.1	555	1670	844	1.04	1.79	1.71	1.73
4		7.0	75.0	75	74.0	18	7.5	9.5	9.5	2.0	57	73	16	56	59	62	60.5	4.5				68.5	20	122	126	-1.1	505	2480	810	1.14	1.85	1.77	1.71
5		7.0	76.0	76	74.5	18	7.5	8.5	8.5	1.0	56	73.5	17.5	55	59.5	62	60.7	5.7				69.	20	137	141	-1.3	574	3325	845	1.04	1.82	1.77	1.69
6		7.0	75.5	75.5	74	18	7.5	8.5	8.5	1.0	56	73	17	55	60	62	61.0	6.0				70.5	20	130	134	-1.1	616	4175	850	1.06	1.72	1.74	1.79
7		6.5	75.0	75	74	18	7.5	8.0	8.5	1.0	57	73	16	55	59	63	61.0	6.0				70.5	20	136	140	-1.2	597	5012	837	1.00	1.55	1.69	1.70

D50 Illuminant, 2 degree observer

	1	2	3	4	5	6	7	8	9
L* =	39.12	65.43	49.87	44.26	50.56	70.82	63.51	39.92	52.24
a* =	13.24	18.11	-4.34	-13.80	8.82	-33.43	34.26	11.81	48.55
b* =	16.07	16.72	-22.29	22.85	-24.49	-0.36	59.60	-46.07	18.51

	10	11 (A)	12	13	14	15
L* =	97.06	92.02	87.34	82.14	72.06	62.15
a* =	-0.40	-0.60	-0.75	-1.06	-1.19	-1.07
b* =	1.13	0.23	0.21	0.43	0.26	0.19
Density =	0.04	0.09	0.15	0.22	0.36	0.51

	16 (M)	17	18 (B)	19	20	21
L* =	49.25	39.62	28.08	16.19	8.20	3.44
a* =	-0.16	-0.18	0.54	-0.05	-0.61	-0.23
b* =	0.01	-0.04	0.60	0.73	0.19	0.40
Density =	0.75	0.98	1.24	1.67	2.04	2.42

	22	23	24	25	26	27	28	29	30
L* =	31.41	72.46	72.95	29.37	54.91	43.96	82.74	52.79	50.87
a* =	20.98	-24.46	16.83	13.06	-38.91	52.00	3.45	50.88	-27.17
b* =	-19.43	55.93	65.80	-49.49	30.77	30.01	81.29	-12.72	-29.46

Colors by Munsell Color Services Lab

Golden Thread
Version# DL1.0

Don Williams


D50 Illuminant, 2 degree observer
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